TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

KIMMO KEKKI

CREATING A NEW FACTORY LAYOUT AND CALCULATING ITS EFFICIENCY

Master of Science Thesis

Professor Petri Suomala has been approved as examiner at the meeting of the Department Council on February 5th 2014

ABSTRACT

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The objective of this study was to develop a Future Factory concept for Metso Mining and Construction (Tampere) Inc. and calculate its operational and financial benefits in comparison to current operations. Future Factory concept involves both the design of the factory layout and the operational systems, which includes the amount of workforce required.

The role of manufacturing operations has become more and more demanding during the past decades. Today, production environment must be flexible, highly productive and still maintain its low assembly cost and high product quality. Metso Mining and Construction Corporation's Tampere factory plant has developed to the state it is now during its 100 years of history. This master's thesis has been made to introduce a totally new concept of manufacturing and support factory's long-term development plan.

This thesis consists of two parts. The first part, theoretical background, which consists of three themes, is designed to support the second, empirical part. Firstly, the theoretical background introduces the basic manufacturing philosophies related to Toyota Production System (TPS) and Lean, which were designed to illustrate the best practices for manufacturing operation. Secondly, the design procedure of a new factory layout was researched in order to define a systematic approach to a new layout creation. Finally, the theoretical framework suggests ways to evaluate the newly created layout's performance compared to the current operations. In addition, benchmarking to corporations having similar assembly operations were made in order to find new ideas outside the company. The empirical part of this thesis uses the created framework to reach the defined objectives.

As a result, the thesis introduces a new master layout for Tampere CSE manufacturing, which covers all the designed operations. The calculations indicate a significant improvement not only in the operational performance related to production lead time, but also in the factory's cost structure. Furthermore, the designed Future Factory concept reveals a strong potential in current operations and the human productivity involved. As a conclusion, the Future Factory master plan suggests key drivers to support the operational change, which are partially feasible in current facilities.

TIIVISTELMÄ

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Tämän diplomityön tavoitteena oli suunnitella Metson kaivos- ja maanrakennussegmentille Tulevaisuuden tehdas-konsepti (Future Factory concept) ja tarkastella sen tehokkuutta operatiivisen ja taloudellisen tehokkuuden näkökulmasta. Suunniteltu konsepti pitää sisällään tehdaslayotin, valmistettavien tuotteiden materiaalivirran sekä karkean suunnitelman tuotteiden läpimenoajoista ja tarvittavista henkilöstöresursseista.

Kokoonpano- ja valmistustoiminnalle asetetut vaatimukset ovat kasvaneet merkittävästi viime vuosikymmenten aikana. Korkean tuottavuuden lisäksi tuotannon tulee olla joustavaa sekä kustannustehokasta, säilyttäen kuitenkin tuotteilta vaadittavan laatutason. Kaivos- ja maanrakennussegmentin Tampereen tehtaat omaavat lähes 100 vuoden historian, jonka aikana vaiheittaiset kehitystoimet ovat muovanneet sen nykyisen kaltaiseksi. Tämä diplomityö puolestaan esittelee täysin uudenlaisen tuotantokonseptin, jonka tarkoituksena on viitoittaa tietä pitkän aikavälin kehitykselle.

Työ jakaantuu kahteen osaan. Ensimmäisessä osassa esitetään teoreettinen viitekehys, jonka tarkoituksena on luoda pohja empiirisen osuuden tueksi. Teoriaosuuden alussa esitellään Toyotan tuotantojärjestelmä (Toyota Production System) sekä Lean-tuotanto, jotka yleisesti mielletään nykyaikaisen tuotantojärjestelmän esikuviksi. Tämän jälkeen kuvataan menetelmät tehdaslayoutin systemaattisen luomisen tueksi. Viimeiseksi esitellään laskentamallit, joilla uuden tehdaslayoutin tehokkuutta voidaan arvioida suhteessa nykyiseen toimintaympäristöön. Kirjallisuustarkastelun lisäksi suoritettiin yritysvierailuja nykyaikaista kokoonpanotoimintaa harjoittaviin yrityksiin uusien ideoiden löytämiseksi tehdaslayoutin suunnitteluun. Empiirisen osan tavoitteena oli saavuttaa työlle asetetut tavoitteet teoreettisen viitekehyksen avulla.

Työn tuloksena esitellään Metson Kaivos- ja maanrakennussegmentin Tampereen tehtaalle uusi tehdaslyout. Suoritettujen laskelmien mukaan sen suorituskyky on huomattavasti parempi verrattuna nykyiseen sekä tuotannon tehokkuuden kuin taloudellisten mittareidenkin valossa. Tämän johdosta Tampereen tehtailla voidaan todeta olevan huomattavaa kehityspotentiaalia omissa toiminnoissaan. Loppupäätelmissä listataan Tulevaisuuden tehdas-konseptissa esiin nousseita käytännön parannusehdotuksia, jotka ovat osittain toteutettavissa myös nykyisessä toimintaympäristössä.

ACKNOWLEDGEMENTS

This master's thesis and the related Future Factory concept has been an unforgettable project for the editor. Several people from Metso Mining and Construction Inc. Tampere and from Tampere University of Technology deserve my sincere acknowledgements from their contribution to this master's thesis.

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The support and encouragent I have received from my family and friends during this master's thesis and my studies have been irreplaceable. I want to express my gratitude to my parents Hannu and Mirja, my sisters Elina ja Kata and to my girlfriend Saara for their valuable support during these many years.

Tampere, on March 6th 2014

Kimmo Kekki

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ABBREVIATIONS AND NOTATIONS

Andon	An indicator showing a problem in the process, typically a light or a screen.
CAD	Computer Aided Design.
ERP	Enterprice Resource Planning. A software designed to master operations such as purchasing, capacity planning and manufacturing scheduling.
FIFO	First-in-First-Out.
Jidohka	Japanese word meaning autonomous defect control. A way to prevent defective work in machines or production lines to move further in the process
J.I.T	Just-In-Time.
Kaizen	Japanese word meaning philosophy of continues improvement.
Kanban	Usually a small plastic card. Indicates the type and amount of products needed to be produced.
LEAN	An ideology of creating as much value as possible with minimum amount of resources.
LT	Lokotrack. A mobile platform for crushing equipment.
MAC	Mining and Construction. One of the Metso business segments.
MES	Manufacturing Execution System. A subsystem for ERP.
Muda	A Japanese word meaning waste.
ST	Screen Track. A mobile platform for screening equipment.
TPS	Toyota Production System. Manufacturing philosophy created in Toyota.
VSM	Value Stream Mapping. Management principle to analyze and improve manufacturing processes.
WIP	Work in Progress.

1. INTRODUCTION

Japanese word kaizen refers to continues improvement and to the idea of making things little better every day (Stevenson, 2009, p.428). However, many ways of development exists, making things little better every day like kaizen or then engineering everything from scratch.

Metso Mining and Construction's Tampere factory plant has almost 100 years of experience from steel manufacturing and machine assembly operations. Furthermore, during these 100 years, manufactured products and requirements have evolved and therefore, especially the oldest facilities and buildings do not match modern standards for industrial facilities. This situation created a motivation for planning concept of a Future Factory and calculating its benefits in comparison to present manufacturing facilities. This master's thesis is made to support this concept and the related long term development plan.

Future Factory project's aim is to develop and re-engineer new production facilities and production processes for Metso Mining and Construction's Tampere factory. Term production process in this case includes all the needed manufacturing operations, which are required to provide customers assembled, tested and painted machines. This mission includes operations such as warehousing and material movement, production planning, testing, packing and dispatching. Furthermore, baselines for a new layout proposals are that they are designed for completely new production facilities and land properties and therefore the master plan is free from related constrains.

The method of calculating Future Factory's performance compared to current facilities and operations will be based on Value Stream Mapping, which is a technique to analyze factory's operations in a big picture. Value Stream Mapping connects strongly to Lean production principles and the basic guidelines from Lean will be introduced in this thesis. In addition, Lean production and its predecessor Toyota Production System illustrate globally the most commonly used production principles and the usability of these principles should be analyzed. (Process Excellence Network, 2012)

1.1 Present situation

Metso Mining and Construction (MAC) Tampere manufactures screening and crushing solutions for global customers. The factory locates nearby Tampere city centre and has started its operation 1915. At the moment, Metso MAC at Tampere has a property off 14 hectares and facilities which include for example two production lines, two sub-assembly lines and several sub-assembly stations. Production lines provide facilities for mobile screen and compact Lokotrack assembly. Sub-assembly stations manufacture small assemblies such as hydraulic blocks, screens and conveyors. Furthermore, factory has two station assembly halls for small and large mobile crushing equipment and another hall for testing purposes. In addition, stationary (without mobile platform) crushers have their own manufacturing stations. Moreover, factory plant includes two paint shops and facilities for warehousing and dispatching. Picture 1 shows the overall view of Tampere factory plant, which in addition to CSE operations includes facilities for Metso MAC Distribution Center and foundry operations.

Picture 1. Aerial view from Metso MAC, Tampere factory plant.

Warehousing operations are both inside and outside factory plant and are located in three main areas. Lokotrack products have their warehousing at two different locations, one at PP-Logistics at Lempäälä and another at Härmälä, Tampere. Mobile Screens warehousing locates mainly at Härmälä. The factory plant itself has a limited amount of warehousing capacity and therefore larger modules are stored outside factory such as frames for mobile platforms. Factory's outside logistic centers are close to the main production plant, Lempäälä locates approximately 15 km from factory and Härmälä in a distance of 5 km.

Demand planning and moreover production forecasting is made by Tampere Order Office with the help of global Sales & Operations-team and Product Management. With the help of this forecast, Order Office creates a production plan for next 12 months, which is specified the closer the actual start of the production becomes. The heart of this is an Enterprise Resource Planning (ERP) system SAP, which controls all the purchasing and manufacturing functions. SAP program has been used for 3 years and new Warehouse Management extension will be launched during this master's thesis. This functionality enables online picking and inbounds logistics operations with a portable, mobile phone size device.

Lokotrack (LT) and mobile screen (ST) manufacturing is done mainly with single-shift operations on each station or assembly line. However, few periods with higher supply demand have been operated with two-shift work. In addition, some machining centers operate on three-shift work and large jaw crushers' assembly on two-shift work.

1.2 Objectives

Customer markets and demand has changed notably during the past 100 years. Bukchin et- al. (2002) reminds that long gone are the days when one could purchase one affordable car and it would be T- model Ford with a black paint on it. In addition, in current market environment product life cycles are short and product variety demands are high. At the same time, customers value short lead time and are extremely price-conscious. As a conclusion, modern production environment must be flexible, highly productive and still maintain its low assembly cost and high product quality. (Stephens & Meyers, 2010)

The guiding objective for this project is to increase the overall productivity and cost-effectiveness of the manufacturing operation. According to Kuhmonen (2011), features such as productivity, lead time, delivery reliability, inventory and quality represent a good production performance. Also Cunningham & Fiume (2003) and Sakamoto (2010) mention productivity as a key to company wealth.

One aspect of this project is to define ideal product mixes to be assembled in production facilities. At the moment the type of machine defines where it will be manufactured. This means that regardless the amount of work hours needed, all the products from the same product group are made at the same production line.

Another objective for this project is improving factory's Make-to-Order principle and transforming it to be truly the principle of delivering products. This connects closely to previous objective of making production lines more efficient. With the help of efficient manufacturing process, products can be delivered to final customers with a minimal lead time and therefore storage for semi-finished products or standard specification machines becomes less important or totally unnecessary. In addition, subcontracting phases such as painting will be examined to shorten manufacturing lead time and decrease manufacturing costs.

Tampere factory's main role is to execute final assembly operations and the actual manufacturing of parts has been mainly outsourced or done by purchasing. However, large crushing parts, for example castings, are machined inside the company. Furthermore, due to complexity of products and high number of parts coming outside the company, material handling and material flow plays a key role in a successful and effective production line, which connects material flow improvements closely to the Future Factory project. As a conclusion, the creation of layouts and the design of material flow to related assembly operations go side to side from beginning of the project until the very end of it.

As a result, the goal for this master’s thesis is to represent tentative, but calculated plan for a new Future Factory. Criteria for a Future Factory is to improve material flow, decrease the size of production facilities and labor hours needed. More precisely, goal for 50 percent decrease in manufacturing space and labor hours is set.

1.3 Boundaries for research

The creation of a factory layout is a massive scale operation and therefore extra attention must be paid for setting boundaries for both research and actual master’s thesis. Therefore, this master’s thesis concentrates mostly on plant level layout and analyzing its performance. Details inside production lines and assembly stations are excluded from this project.

Theoretical parts of the thesis will concentrate on three major subjects:

- Toyota Production System and Lean production principles,
- Theories and practices for manufacturing facilities design and
- Process analyzing tool Value Stream Mapping

Lean production principles and tools are tentatively suitable for implementing change in the company. VSM’s purpose is not only to help focus on correct areas in production, but also to evaluate Future Factory’s performance in comparison to current facilities. In previous researches Value Stream Mapping has proved its efficiency when concentrating on plant level operations and it has the ability to show all manufacturing related operations. In addition, information flow, which is essential part of operations, can be viewed with VSM.

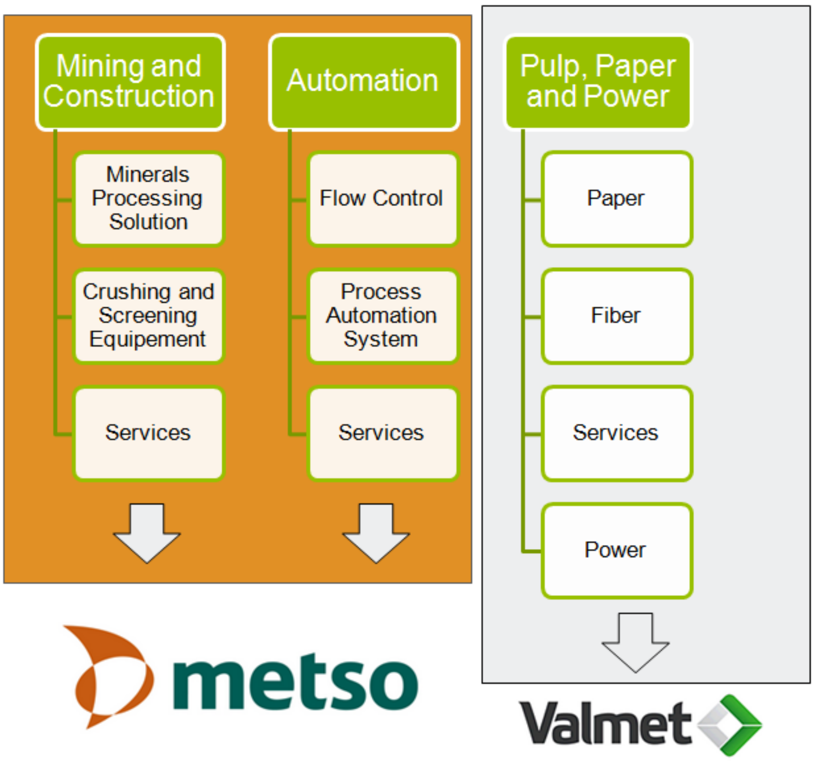
Empiric parts of thesis start by gathering data from current operations. It is vital to generate a good picture from present situation to be able to know which operations for example create bottlenecks in material flow. One major part of Future Factory project is to create a new production layout. VSM will be used to analyze new production layout’s performance in comparison to current layout. In addition to the theoretical research, best production practices will be searched via benchmarking to advanced productions facilities inside Finland and by organizing workshop inside the factory to gather ideas for a new layout plan.

2. METSO MINING AND CONSTRUCTION TAMPERE

2.1 Metso Corporation

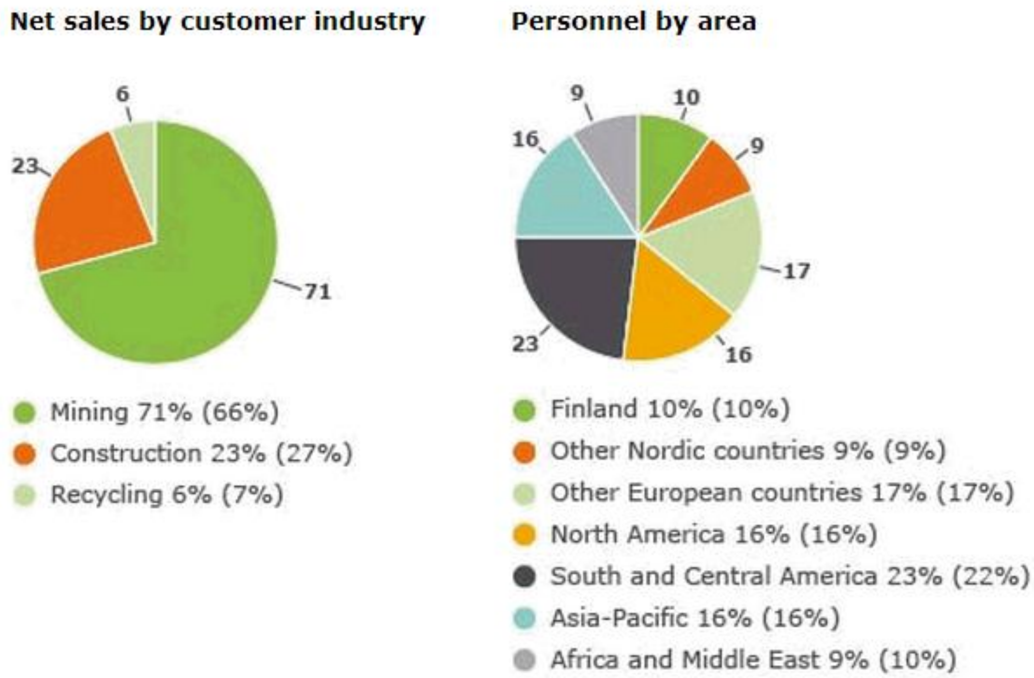
Metso Corporation's predecessor Lokomo Oy started its operation 1915 by manufacturing steam locomotives. Although name Lokomo is used commonly as Metso Mining and Construction's Tampere factory plant, Lokomo as a corporation name was lost in 1970's when company called Rauma-Repola acquired Lokomo. In 1999 Rauma and Valmet merged becoming a new corporation called Metso Group. Few years later in year 2001 Metso Group was divided into three segments, Metso Automation, Metso Paper and Metso Minerals. Nowadays three Metso business lines are named Metso Mining and Contruction (MAC), Metso Automation and Metso Pulp, Paper and Power.

However, during this master's thesis Pulp, Paper and Power business line will demerge into own corporation from the beginning of 2014, taking a traditional name of Valmet Corporation. Current business lines and the situation after demerge are shown in picture 2.



Picture 2. Metso Corporation and upcoming demerge to Valmet. (Metso, 2013)

Today Metso has globally over 30000 employee and its sales in 2012 were EUR 7504 million, where 46 percent came from Mining and Construction. Net sales inside MAC per customer industries and locations of employees are presented in picture 3.



Picture 3. MAC revenue per business segment and employee locations. (Metso, 2013)

Metso Mining and Construction in Tampere has about 1000 employees, which are approximately divided evenly to blue-collar and white-collar workers. Furthermore, from those employees, crushing and screening equipment business line (CSE) has 350 employees, from which 90 comes from white-collar and 260 from blue-collar.

Tampere Factory plant serves global customers. Although geographical location favors European and Middle-East markets due lower shipment costs, deliveries are made worldwide.

2.2 Metso Mining and Construction Tampere product groups

MAC Tampere manufactures a large variety of mobile and stationary crushing and screening equipments. Products can be divided into three categories: stationary crushers, mobile Lokotracks (includes crusher) and mobile screens. Furthermore, crusher manufacturing in Tampere includes cone (GP-series), jaw (C-series) and impact (Barmac-series) crushers. More exactly, Tampere factory manufactures over 20 different crushers and over 20 different Lokotracks or mobile screens. The sizes of the crushers vary from

8 tons gyratory crusher GP200 up to 78 tons jaw crusher C160. To sum up, Tampere factory has large amount of different models, which is further growth by different selectable options. Therefore, the large number of different products combined with relatively small production volumes brings the production into large variety-low volume type manufacturing environment.

2.2.1 Crushing solutions

The oldest and at the same time Metso MAC's most important products are its crushing solutions. Crushers represent about half of Tampere production volumes, from which two thirds goes to mobile Lokotracks. In year 2012, factory produced about 400 crushers in total.

Crushing solutions differ from Lokotracks and mobile screens in a way that factory manufactures partly its own components from raw casting. This means that the largest modules such as gyratory's upper and lower frame castings and hot-rolled steel plates are machined inside the factory. In addition, subcontracting for machining is being used according to the situations in machining capacity and demand. Picture 4 represents the Jaw Crusher C125.

Picture 4. C125 Jaw Crusher (weight 40t). (Metso data bank, 2013)

2.2.2 Lokotrack mobile crushing plants

Metso Lokotrack mobile crushing plants are divided into three categories depending on a crusher type. Three categories are

- Lokotrack Jaw plant,
- Lokotrack impactor plant and
- Lokotrack cone plant.

Jaw Lokotrack plants differ from 28 tons LT96 up to LT160 weight in at around 215 tons. Small and medium size Lokotracks can be transported as one-piece to final customers whereas larger Lokotracks must be disassembled for dispatching and transport. Picture 5 shows the LT120 Lokotrack at its natural environment.

Picture 5. LT120 working on a site. (Metso data bank, 2013)

2.2.3 Lokotrack mobile screens

Metso mobile screens represent the youngest product group in factory’s history. First mobile screens were manufactured in 2008 and production types have changed between station and line assembly. Today mobile screen product group includes five models with two screening methods. These two methods differ from material processing direction. ST2.X series machines are being built to primary processes where oversize products go straight forward with the help of punch plates or plate grizzlies on screen’s top deck. ST3.X series and ST4.8 use slightly more complex screening method, where long feeder conveyor raises material to screen’s upper end and material direction changes during the process. Picture 6 shows the ST4.8 mobile screen.

Picture 6. Metso ST4.8 Mobile Screen. (Metso data bank, 2013)

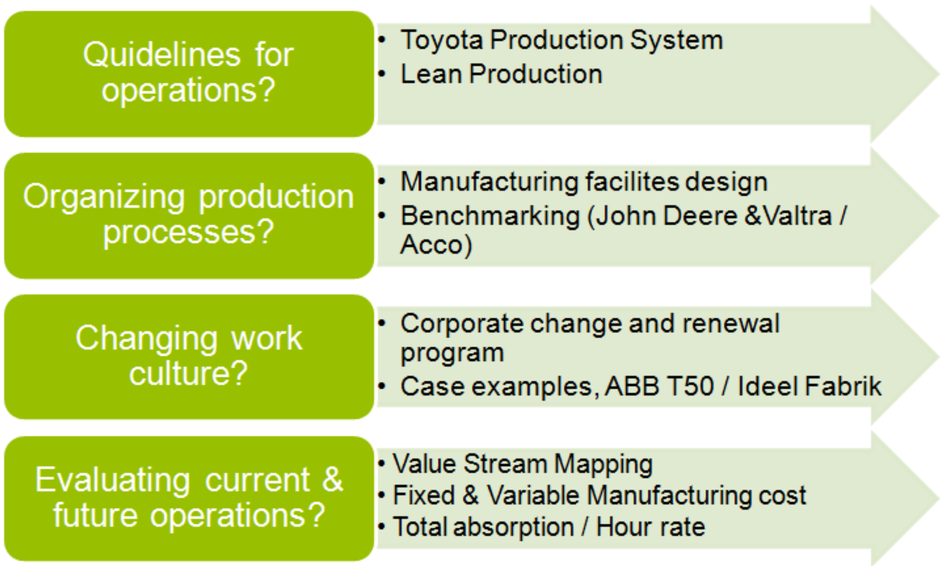
3. THEORETICAL BACKGROUND

Theoretical background section introduces main philosophies and methods, which have influenced the creation of a new layout and the evaluations of its results. The theoretical section can be divided into three categories:

- Manufacturing philosophies based on Toyota Production System and Lean,
- Tools to create new factory layout and
- Ways to evaluate current and newly created layout's performance (VSM).

Diagram 1 explains the theoretical questions brought up in the project and the planned solutions to the questions.

Diagram 1. The structure of the theoretical background.



3.1 Lean production

Lean manufacturing philosophy and more precisely its predecessor Toyota Production System goes back to times after World War 2, when car manufacturer Toyota started improving its manufacturing operations (Liker 2004, p.22-25). At the beginning, Toyota Production System (TPS) spread widely among Japanese companies after the oil shock 1973 (Monden 1983, p.1). Furthermore, much later the word "Lean" was first introduced in article "Triumph of The Lean Production System" published by John Kraftik in 1988. Article chose to represent Toyota's manufacturing philosophy with the name *lean*, because the concept was to perform operations with minimal resources (Krafcik 1988, p.44-45).

Toyota Production System concentrates on removing unnecessary elements from production in purpose of cost reduction. The basic idea is to produce the right kind of units needed, at the time needed and in the quantities needed. By realizing this concept, all unnecessary intermediate and finished goods inventories can be eliminated (Monden 1983, p 2).

3.2 Toyota Production System

Toyota Productions Systems main goal is the cost reduction. However, cost reduction can only be attained with three additional subgoals:

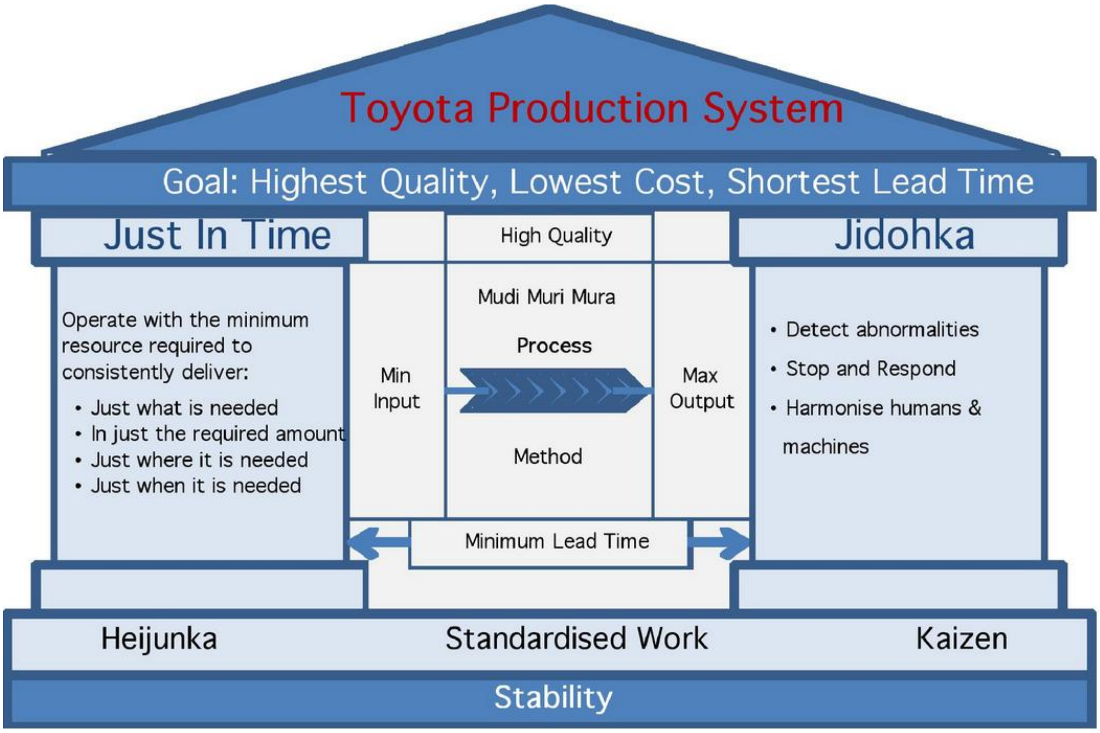
- Quantity Control
    - Enables the system to adapt daily and monthly fluctuations in demand in terms of quantities and variety.
- Quality Assurance
    - Assures that only good quality units will be supplied to subsequent processes.
- Respect-for-humanity
    - Must be cultivated while the system utilizes the human resource to attain its cost objectives (Monden, 1983, p. 2).

TPS emphasizes that these three subgoals cannot exist independently or be achieved independently without influencing each other or the primary goal of cost reduction.
The strong connection of these sub- and primary goals is a special feature in Toyota Production System and the main goal cannot be achieved without respecting subgoals and vice versa. In addition, these goals are only outputs from the same system, where productivity is the ultimate purpose and guiding factor for all actions.
(Monden, 1983, p 5)

These goals are supported by two key pillars to secure continuous flow of production or adapting to demand fluctuations in quantities and variety; **Just-in-Time production and Autonomation.** Just in Time means that necessary units are produced at necessary quantities at the necessary time. Therefore it connects to the first subgoal of quantity control. Autonomation can be described as an autonomous defects control. On that account, it is part of second subgoal of quality assurance by means of preventing defective parts to continue in process. In addition, autonomation helps second main concept Just-in-Time production to succeed by preventing defective units from a preceding process to continue in the production flow. (Monden, 1983, p. 12).

Another, visual way of representing this manufacturing philosophy is called the “TPS house”. TPS house is one of the recognizable symbols in modern manufacturing. The concept is named “house”, due to its structural system, where everything links together. There are various versions of the house, but the basic idea stays the same. The house starts with the goals of best quality, lowest cost and shortest lead time - the roof. The roof is supported by two pillars, Just-in-Time and Jidoka, which means never letting a defect parts pass into the next station. Finally, the foundation elements, which include the need for standardized, stable and reliable processes, continuous improvement (kaizen) and leveled production (heijunka) are as important as the roof and pillars. In addition, other philosophies can be added to foundation such as “respect for humanity”. (Liker, 2004, p. 32-34)

The principles of the Toyota Production System are shown in picture 7.



Picture 7. Toyota Production System (1Tech, 2013)

3.2.1 Just-in-Time production

The first basic pillar of Toyota Production System is named Just-in-Time production. The idea is to produce necessary units in the necessary quantities at the necessary time. Practically this means, for example in a car manufacturing that the needed subassemblies from previous processes should arrive at the product line at the time needed, with the right quantity. Furthermore, when the level of subassemblies and parts exceeds thousands, central planning approach where all processes are scheduled simultaneously becomes almost impossible to maintain successfully. This dilemma has been a driving force in Toyota to look at the production flow controversially and build-in the scheduling into the processes. For example, the employees from certain processes go to the preceding operation to withdraw needed parts. After this, the preceding operator produces the right amount of parts needed to replace the withdrawn ones. This guiding information about units and quantities is usually written on a taglike card called Kanban (Monden, 1983, p 35).

Kanban card system is sometimes confused as a synonym to Toyota Production system. However, TPS is the basic productions system to make products, whereas Kanban supports Just-in-Time production and the way of controlling material flow. (Monden, 1983, p. 36). Physically Kanban is usually a small card inside a plastic envelope. On the card, there is information about part number, quantity inside the container and the point of delivery. Furthermore, in order to work properly, Kanban system requires all designed solutions and production principles to support this idea. These solutions involve smoothing of production, reduction of setup times, functional design of machine layout and standardization of jobs (Stevenson, 2009, p. 694).

Smoothing of production is necessary due to linkage between processes where subsequent processes go to the preceding processes to withdraw the necessary goods. Under such a production rule, where subsequent processes withdraws parts in a fluctuating manner, will build up excess resources to inventory, equipment and manpower in case of a peak in the quantities needed. In addition, simultaneous sequenced processes may increase this variance when moving further back to preceding processes. (Monden, 1983, p. 6)

As a conclusion, in order to prevent such large variances in all production lines and subcontracting, an effort must be made to minimize the fluctuation in further assembly operations, for example in final assembly line. For this reason, Toyota’s final assembly line of cars will convey each model of automotives in its minimum lot size, realizing conveyance and the ideal of **“one-piece” flow**. (Cunningham & Fiume, 2003, p. 8)

In practice, smoothing of production means creating a production mix, where at the same time production schedule fulfills the customer demand and the one-piece flow principle. The biggest advantage of smoothed production is the ability to adapt smoothly and quickly to the variations in customer demand. However, the decrease of lot sizes without decreasing total production volumes will demand shortened setup times. (Monden 1983, p. 7)

Reduction of setup times and the importance of it originate from the smoothing of production and the reduction of lot sizes. In a typical manufacturing operation, common sense dictates that cost reduction is most easily obtained by allowing the biggest lot size and thereby reducing setup costs. However, demand generated from balanced operations from downstream, which have already averaged their production and reduced their inventories, require frequent and speedy setups. (Monden, 1983, p. 8)

The key to reductions of setup times becomes possible by separating different setup processes; **external setup and internal setup**. External setup refers to operations which can be performed beforehand or after the actual operations. These operations include for example preparing necessary jigs and tools for operations and removing used jigs and dies after the machining center starts operating new parts. Internal setup means the opposite for all this. All the setup actions performed when the machine is stopped are called internal setup. The key to reduction of setup times is converting all the possible actions from internal setup to external setup. (Monden, 1983, p. 25)

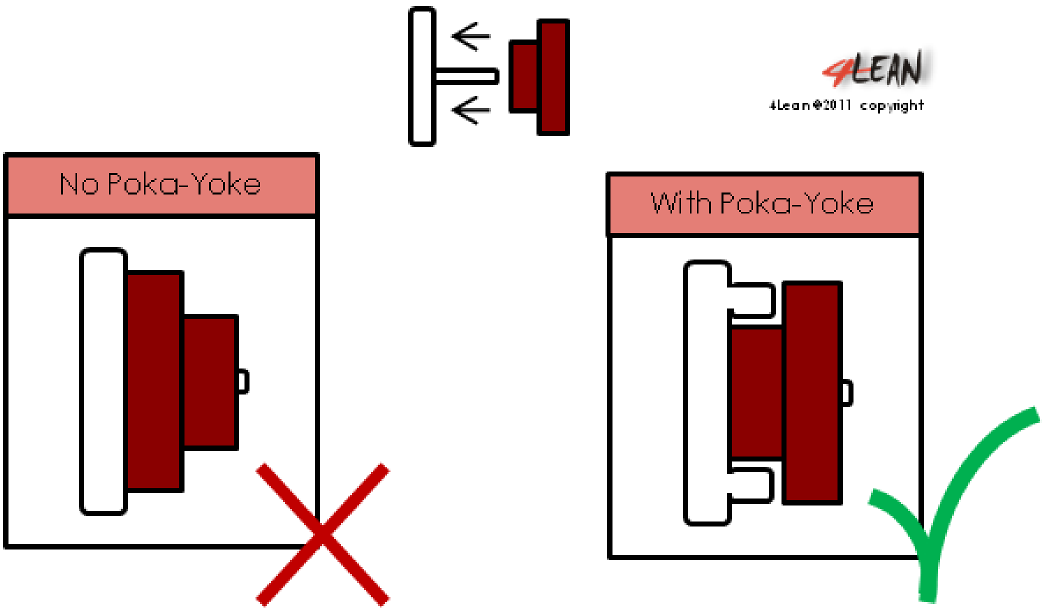
Although reduction of setup times in highlighted in the Toyota Productions system, it does not play a major role in Metso type final assembly. This is due to relatively long cycle time and thereby a minor overall percent of setup times. However, operations such as painting have similar qualities, which can be divided to external and internal setup. In addition, the idea of sub-assemblies is highly similar to the idea of external and internal setup. By creating sub-assemblies, the labor needed in the main assembly can be shortened if necessary. By that means the load of the main assembly can be balanced.

Design of machine layout or more generally manufacturing layout is an important factor when concentrating on production flow. Well designed production flow prevents material from backtracking and enables employees to operate several machines at the same time instead of just one. In TPS, this system is called multi-process holding. In other words, previous single-function worker is now able to operate several machines at the same time and thereby has become a multi-function worker. Multi-function workers enable certain production lines to be balanced in a way that new units are introduced at the same pace with the completion of finished products at the other end and thereby building no inventories between stations. This production method is also called one-piece production. This type of one-piece production will be followed with other positive benefits such as elimination of unnecessary inventories between processes, decreasing the number of workers needed and enabling workers to perform versatile tasks inside factory and thereby feeling better about their jobs. (Monden, 1983, p. 100)

Standardization of jobs refers to having similar practices around factory such as common document models, standardized instructions and clear visible goals. (QDC training material, 2013). Toyota Production System has two kinds of sheets to show standard operations: **the standard operations routine sheet** and **standard operations sheet**. The standard operations routine sheet is basically a man-machine chart, which chops operations to small parts. The standard operations sheet shows cycle time, standard operations routine and standard quantity of the work in process. (Monden 1983, p 87)

Autonomation is a way to secure on-time rhythmic flow with 100% good units to subsequent processes. In other words, autonomation is a way to prevent defective work in machines or production lines to move further. (Monden, 1983, p. 15) Autonomation can be descriped as automation with human touch. Furthermore, autonomous machine can be described as a machine, which has an automatic stopping device (Stephens & Myers, 2010, p, 10).

One type of autonomation is called Foolproof or Pokayoke. Furthermore, Pokayoke is a device that makes it impossible for an operator to make an error (Liker, 2004, p. 133). Pokayoke method can be used by putting checking devices on the machines to alert human or mechanical errors (Monden, 1983, p. 16). Picture 9 shows an example out of Pokayoke design.



Picture 9. Pokayoke example (4Lean, Lean tools, 2013)

However, autonomation in not just connected to automated production lines, but can be expanded to manual work. For examble, if something abnormal happens in the production line, employee pushes a stop button to indicate failure in the process. Thereafter a light called *andon* turns on and shows that the employee has a problem. Typically a red light indicates a major problem, which leads to stopping of production line whereas yellow shows that employee need instant help to continue without line stoppage. (Stevenson, 2009, p. 707)

The concept of cost can be described as cash outlay in the past, present and future reduced from sales revenue to get a profit. Furthermore, concept of costs includes not just manufacturing cost but all the cost related to operations such as administrative cost, inventory cost and sales cost. The basic idea behinds these tools and principles of Toyota Production System is to increase profits by decreasing costs. Things such as inventory, rework and scrap cost money, which therefore should be eliminated. In other words, waste elimination has a specific purpose and it is not just a vague principle. To sum up, the idea inside TPS is to be extremely cost conscious whether it considers designing, producing or delivering products to customers. Furthermore, whereas Lean is mostly about flow, value and customer satisfaction, TPS is not that simple. TPS is much more business oriented, the fundamental purpose is to make profit. (Smalley, 2005)

3.2.2 Waste reduction: Muda

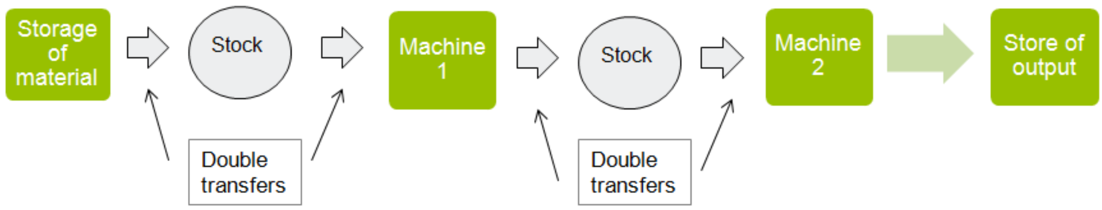
Muda is a Japanese word meaning waste. Furthermore, whereas Muda refers to more common waste such as transportation, two other types of wastes exist; Mura and Muri. Mura is a waste related to inconsistency and Muri to overburdening of people and equipment. (Liker, 2004, p. 114). Lean and TPS philosophies have many similarities, for example eliminating waste is a crucial part of both principles. (Cunninham & Fiume, 2003, p. 44). Finally, both TPS and Lean have several tools or techniques to fulfill these goals, such as Lean 5S or Toyota Just-in-Time (Liker, 2004).

Taiichi Ohno originally presented 1988 seven types of Muda. These were overproduction, waiting, transportation, extra processing, inventory, movement and waste of making defective products.

Overproduction exists, when operations should be finished, but they are still performed. This means for example finishing materials to a higher accuracy than needed for the functionality of part or exceeding the quality needed from the customer perspective.

Waiting is a waste that is generated through the inactivity period caused by machines or workers. Waiting is usually due to lack of synchronization between operations or delay from outside services or materials. For example, situation where preceding process cannot deliver parts to upcoming operations to be assembled is considered waiting.

Transportation means unnecessary transports between operations. This category includes also deterioration and damages that happen during the transportation. One type of unnecessary transportation happens when work-in-progress inventory must be delivered to storage and it cannot be transported straight to following operation. Example from this double transfer is showed in picture 10.



Picture 10. The double transfer caused by intermediate stock (Monden, 1983)

Extra processing refers to fixing once already finished materials. Usually extra processing is due to bad storage conditions or careless movements between storage and transportation devices, for example forklifts. Re-painting due to corrosion of once ready products is also considered extra processing.

Inventory is referred to waste due to its nature of binding factory's working capital and at the same time adding no value to operations. Excess inventory will also require storage capacity and cause inventory carrying cost.

Movement is unnecessary motion of employees, materials or machines.

Waste of making defective products means manufacturing products that do not response to quality standards from customers. In addition, the materials from suppliers which are rejected (not suitable for assembly) represent this waste.

In addition to these seven sins of waste, modern thinking of Lean includes one extra to the list. Latent skills or unused human resources can be viewed as the last waste. Although organizations hire employees for their specific skills, it would be unreasonable to use their additional talents to eliminate the other seven sins. (Liker 2004, p. 29)

3.2.3 Types of manual operations

The manufacturing of parts usually acquires both manual and automated operations. In every factory, manual operations can be divided into three different categories. These categories are pure waste, operations without value added and net operations to increase value added. (Monden, 1983)

Pure waste is altogether operations, which should be eliminated immediately, for example waiting and unnecessary transportation. Operations without value added refers to operations, which primarily do not add value, but are necessary under present operating procedures. These operations include for example picking parts from long distances or unpacking vendor parcels. Finally, net operations to increase value added are the actual manufacturing and assembly operations such as machining parts and painting framework. (Monden, 1983, p. 117-118)

The actual value adding operations usually represent only a small part of total work hours and the major portion of operations only increase cost without increasing any value. Therefore, by raising the percentage of value adding operations, the labor required per product can be reduced. Obviously, the first step is to reduce as much pure waste as possible. Secondly, the amount of operations without value added should be reduced to minimum with current facilities. Finally, value adding operations should be examined to see if they can be further expanded and thereby increase the value adding proportion. (Monden, 1983, p. 118) Furthermore, these three categories will create the foundation for Value Stream Mapping in evaluating operations value to customer. (Learning to See, 1999)

3.3 Manufacturing facilities design

Manufacturing facilities design refers to the company's physical assets to support efficient use of resources such as people, energy and material. Furthermore, facilities design includes things such as plant location, building design, plant layout and material handling systems. (Stephens & Meyers, 2010, p. 2)

Although plant layout decisions are usually made at the highest corporate level, all other aspects can be locally challenged. Manufacturing facilities design and material handling have the biggest impact on company's productivity and profitability than any other company decision. (Stephens & Meyers, 2010, p. 2) Manufacturing facilities design is the key to arrange production functions and processes physically in way that eliminates unnecessary things such as movement and waiting (Cunningham & Fiume, 2006).

Layout is the physical arrangement of production machines and equipment, workstations, people, location of materials and material handling equipment. Although creating of a new layout is one of the goals for this project, most often layouts are modified and thereby created retrofits or relayouts. The need for modification usually arises from the changes in demand, products or processes or most often from combination from those three. (Stephens & Meyers, 2010, p. 2)

Material handling is one of most important factors inside layouts. Furthermore, especially in businesses, such as Metso Mining and Construction, which concentrates mostly on assembly operations, material handling will account significant portion of all operation costs. It has been estimated that 40 to 80 percent of labor cost is due to material handling. In addition, material handling represents about 50 percent of industrial accidents. (Stephens & Meyers 2010, p. 3)

Improving material flow with new facilities layout has been one the key drivers with this project, because material flow has a direct impact on cost reduction. Moreover, the shorter the distance material travels the higher cost reductions can be achieved. (Stevenson, 2009)

3.3.1 The goals of manufacturing facilities design

A large project such as designing a new manufacturing layout needs goals for designers to be able to concentrate on right things. In addition, goals have the ability to function as a self-regulatory way of helping people to prioritize tasks. Without these targets, employees such as facilities planners are without a direction. (Shalley, 1995)

Stephens and Meyers (2010) argue, that a mission statement is the first step of goal setting. A mission statement announces company's primary goals and the culture of the organization. It also defines the purpose for the existence of enterprise. Principle for mission statement is that it should be short enough so its essence is not lost and it can be easily remembered. Furthermore, mission statement should be timeless and thereby easily adaptable to changes in organization. (Stevens & Meyers, 2012, p. 6) However, these wide recommendations usually drive the mission statement to be a vague statement, which rarely gives any practical direction to designers. For example, Metso Corporation's mission; "We contribute to a more sustainable world by helping our customers to process natural resources and recycle materials into valuable products" focuses more on creating brand image than setting any manufacturing related goals. (Metso, 2013) Furthermore, production goals and objectives should be consistent with the mission and therefore they should be easily derived from the mission statement. (Stevens & Meyers, 2012, p. 7)

In addition to mission statement, project subgoals are presented to support achieving more specific goals. In a project, potential subgoals may include:

- Minimizing project costs

However, this does not mean buying the cheapest machines available because more expensive ones could maintain lower unit price in a big picture. In addition, production volumes may be low and therefore investments prioritized. First of all, **all investments must be cost justified**.

- Optimizing quality

Optimizing quality is an essential part of manufacturing facilities design. Quality and cost are the two competitive fronts. To be precise, products must be produced at the level customers can afford it. After suitable design criteria for parts has been chosen, any cost spend to create parts with better quality will be money misspent. After defining the right level, facility planner selects the equipments, design workstations and establishes work methods so factory is able to produce quality parts and assemblies.

- Promoting the effective use of resources

These resources include people, energy, space and equipment. In other words, this means reducing cost and eliminating muda. People or employees effort is valuable and therefore it should be used efficiently. For example, locker rooms and services related to production such as spare tools should be located optimally.

Sustainable and effective use of energy is both economical and environmental factor for a company. Energy expenses are usually a million dollar scale and therefore with right actions energy savings can be significant. For example, isolating heat sources can reduce remarkably the energy needed for cooling.

Space is costly and its all dimensions should be used effectively. This refers to the concept called “utilizing the building cube”. Facility planners usually concentrate using floor space effectively, but underestimate other possibilities such as the space under the floor and overhead (above 2,5m). Furthermore, good layout procedures will include everything required to operate that workstation, but no extra space.

- Investment on employee safety and convenience

Investments to convenience and safety are important to make employee environment attractive. These factors include for example employee entrances and parking lots. In addition, investment to these factors indicates to employees that company cares for them or vice versa, inconvenient solutions and services show that the company does not care for their employees. Furthermore, employee safety is a must have factor for both employees and company. Every decision made concerning manufacturing facilities design must include safety considerations and consequences.

- Reducing excessive inventory

Inventory carrying costs is normally between 20 and 35 percent year to hold (Hakala, 2013). Therefore, calculating inventory carrying cost shows that a company with tens of millions worth inventory has millions of euro inventory carrying cost annually. Inventory carrying cost percentage is an estimate from expenses such as:

  - The cost of space and its supporting cost (i.e. energy)
  - The cost of money tied up in the inventory
  - The cost of employees required to move and manage the inventory
  - The loss due to damage, obsolescence and shrinkage,
  - The cost for material handling equipment

- Building flexibility into the plan.

Even though all manufacturing facilities plans would be based on accurate calculations and forecasts, there is always a need for flexibility. Therefore a design should anticipate where to expand if necessary and select the type of buildings that support various types of usage. (Stephens & Meyers, 2010, p.7-12)

3.3.2 The manufacturing facilities design procedure

Manufacturing facilities design should always be a systematic process and decision should be based on data. Furthermore, the quality of the final blueprint depends on how well the planner collects and analyzes the basic data. In addition, facility planners should resist jumping into the layout phase, because a systematic procedure would otherwise almost automatically generate a well-grounded master plan. (Stephens & Meyers, 2010, p.11) A systematic approach includes following procedures:

1. **Determine what will be produced.**
   According to Larco et- al. (2008, p 39) the first step in manufacturing facilities design is to determine what needs to be produced. This happens through understanding where markets have been, where markets are going and what are the company's strategic goals. In addition, Stephens & Meyers (2010) argue that marketing department is able to give valuable information about demand and characteristics such as seasonality in demand.

2. **Determine how many will be produced.**
   Valuable information can be examined from the company's order office, which has the latest information about future sales forecast. (Rontu, 2013)

3. **Determine which parts to buy and which ones to make.**

4. **Determine how possible self made parts will be fabricated.** This is also called process planning.

5. **Set time standards for each operation.** Time standard can be defined as a time required of making a product at a workstation with the three following conditions: (1) a qualified, well trained operator; (2) working at a normal pace; and (3) doing a specific task. More precisely, a qualified, well trained operator means that the operator should be experienced worker and he should have at least two weeks time to practice that certain task. Furthermore, normal pace represent a pace that trained operator can comfortably maintain. Finally, a specific task is a task which has the description of needed actions including prescribed work methods, tools being used and material movements. (Stephens & Meyers, 2010, p.52) Defining accurate time standards is important, because usually manufacturing goals are at the beginning dependent on them. (Memo Agco, 2013)

6. **Determine the sequence of assembly (or *assembly line balancing*)**. The purpose for this is to even the workload between work stations. Assembly line balancing can be accomplished by breaking down the tasks that need to be performed and by reassembling them into jobs to the same length of time. Once the

tentative order has been defined, it should be re-evaluated for manufacturability (Memo Valtra, 2013, Memo John Deere, 2013). There will be always a station that has the highest workload. This station is called **100% loaded station or the bottleneck station**. The key of improving assembly line is to concentrate on improving 100 percent station. For example, if you improve your 100 percent station by 1 percent, it means that your whole production line can move 1 percent faster. With 200 people, 1 percent improvement means reduction of two people. This multiplier is a useful tool for example when calculating pay pack times for investments to improve bottleneck stations. (Stephens & Meyers, 2010, p.62)

7. **Determine the plant rate (takt time) in relation to phase 2**. At this point, the fundamental difference between takt time and cycle time should be defined. Firstly, takt time is an expression of customer's demand normalized and leveled over the time you choose to produce. However, with different time period takt time is not a pure customer demand signal due to its round up figure. Furthermore, takt time cannot be used to schedule production, because it would cut off all time from other tasks, for example improvement projects. The formula of takt time is represented in equation 1.

$$Takt\,Time = \frac{Effective\ \ Daily\ \ Operating\ Time}{\mathrm{Re}\,quired\ \ Daily\ Quantity\ of\ \ Output} \qquad (1)$$

Secondly, cycle time is the time certain tasks take from employees to execute. Thereby, these individual tasks may or may not be balanced to the takt time.
Reasonable cycle time is influenced for example by parts weight, size and complexity. The larger the parts, the longer the cycle time would be. However, long cycle times will not support production flow with the same extend compared to shorter cycle times. In addition, job tasks are easier to learn with short cycle times due to the reduced number of operations. Finally, employees favor longer cycle times, because usually it diversifies assignments. (Rother & Harris 2001, p. 16, Baudin 2002, p. 55).

8. **Determine the number of machines needed.** With assembly plant this name is misleading and it should be "the number of workstations". By reproducing the formula of machines needed (Stevenson, 2009), the theoretical minimum number of workstations can be calculated with following equation 2.

$$N_{min}=\frac{\sum t}{\text{Takt time}} \qquad (2)$$

N_{min} = Theoretical minumum number of stations
$\sum t$ = Sum of task times

9. **Study the material flow patterns to establish the best flow possible.** Flow analyzing techniques can be used such as flow diagram. To be precise, flow diagram shows the whole path that parts move from receiving to shipping. It illustrates the heavy traffic centers and also places where unwanted movements such as cross traffic and backtracking occur. Goal for flow analysis is to eliminate as many steps as possible, then rearrange operations to eliminate cross traffic and backtracking and reduce overall distance travelled (Stephens & Meyes, 2010, p. 162). Flow diagram is an effective tool due to its visual appearance and it is able to give instant results (Memo John Deere, 2013).

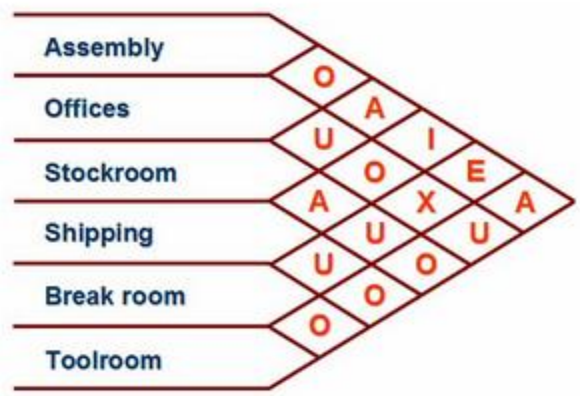
10. **Determine activity relationships.** This means finding an optimal balance in locating operations. Useful tool for finding activity relationships between operations is called **activity relationship diagram.** The procedure is to define about the relationship of every department, office, or service facility with every other department, office, or service facility. The diagram is filled with codes that represent the importance of that certain relationship. The codes can be for example letters. The meaning of letters in demonstrated in table 1.

Table 1. Definitions of codes (Stephens & Meyers, 2010, p. 176)

Letter	Definition
A	Absolutely necessary that these two departments be next to each other
E	Especially important
I	Important
O	Ordinary importance
U	Unimportant
X	Closeness undesirable

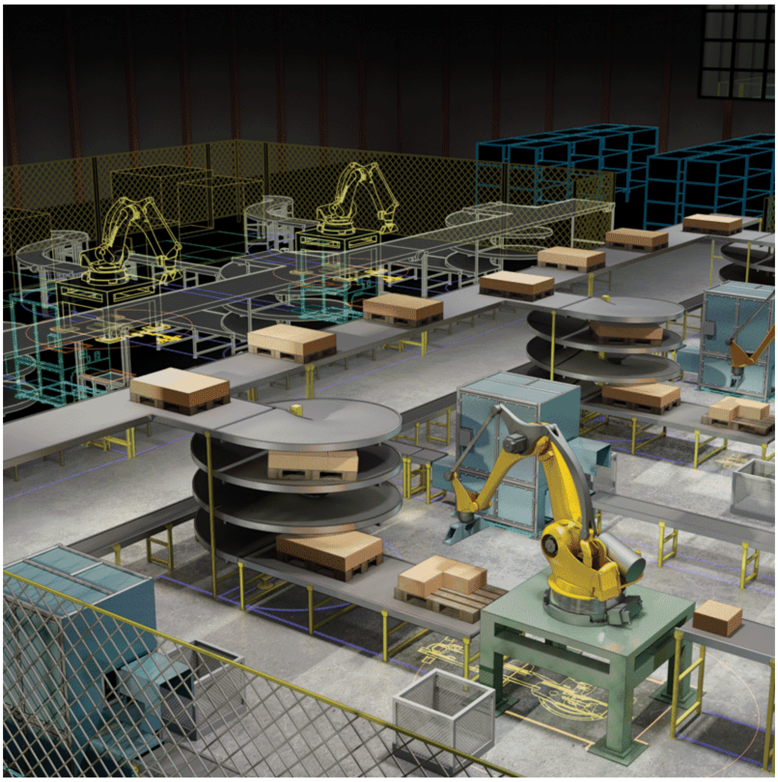
Furthermore, the letters can be replaced with numbers, where positive numbers indicate favorable relationships and negative ones unfavorable relationships. (Chien, 2004) However, when using letters as indicators, additional data can be added to explain selection criteria for later investigating. This data can be for example numbers, where for example number 1 would mean better flow or number

2 indicating heavy people movement. Finally, letters or numbers indicating highest importance between relationships should be used rarely. A good portion follows Pareto analysis approach, where the amount of highest indicators is about 5 percent of all indicators. (Stephens & Meyers, 2010, p.178) Example from activity relationship diagram is shown in picture 11.



Picture 11. (Lean Sigma Supply Chain, 2014)

11. **Make layouts for each workstation** and extend workstation layout to department layouts. Nowadays, factory layouts are drawn with computer aided-design programs due to their high level of details and ability to do quick and easy iterations. In addition, by integrating the routing data with layout information, design programs can calculate benefits from different layout options. (Stephens & Meyers 2010, p. 159). Furthermore, when doing a retrofit to an old layout, CAD design programs are effective and quick to utilize, especially if existing sketches occur. (Memo John Deere, 2013). Factory design programs can evaluate multiple what if-scenarios to determine the best solution before any equipment needs to be installed (Autodesk training material, 2013). An example from 3D layout view is showed in picture 12.



Picture 12. Autodesk Factory Design Suite (Autodesk training material, 2013)

However, integrating 3D with other operative systems such as enterprise resource planning (ERP) has not been that successful yet. Reason behind this seems to be, that manufacturers are only now getting up-to-speed with the integration of manufacturing execution systems (MES) and enterprise resource planning (ERP) systems. After the ERP, MES and 3D layout design tools become more commonly used, the full potential between data for facility design and production operations will be accomplished and the picture about digital manufacturing will be completed. Although, digital manufacturing is exploitable in all business environments, it makes more sence in the complex manufacturing environment. (Will Digital Manufacturing Fulfill its Promise. 2012)

12. **Identify needs for personal and plant services.** These activities include for example locker rooms and health care station.

13. **Identify office space requirements.** Office space can be calculated with multiplying the average number of office employees with 18 square meters or using current office space amount divided by number of employees to estimate space needed per person.

14. **Sum up total space requirements from all facilities needed.**

15. **Select material handling equipment.** The ultimate goal for selecting right material handling equipment is to reduce the costs of production. However, with the right material handling equipment several subgoals can be achieved:
    - Reduce damage during movement
    - Improve safety and working conditions
    - Promote productivity (i.e. decrease travelled distances and automate material handling)
    - Promote the use of building cube
    - Control Inventory

    Furthermore, material handling equipment must be cost justified and chosen case specifically. For example, the equipment suitable for mass-production might not be suitable for low volume-high variance environment. (Stephens & Meyers, 2010, p.277, Memo Agco, 2013)

16. **Make a plot plan and sketch buildings**. In addition, study how buildings and roads would fit into the property.

17. **Construct a master plan**. This is the last phase of making tentative suggestions about manufacturing facility design. Master plan should gather all the data collected and the decisions made since project started.
    (Stephens & Meyers, 2010, p.12-14)

Stephens & Meyer reminds that this list is only suggestive and necessarily all phases must not be examined. In addition, even though first proposal of master plan would be ready, it is highly recommended to ask review about the master plan from managers and co-workers. These iterations and changes are normal and work as an excellent tool to even upgrade the master plan.

One of the aspects that cannot be emphasized enough when doing a new layout is the data backing it up. On old cliché, “garbage in, garbage out” is valid with the layout design. Furthermore, integrity of the input data should always be ascertained, because the output of the system is only as reliable as the input data.
(Stephens & Meyers, 2010, p. 446)

3.4 Concept of corporate change and renewal program

The change of corporate climate and culture has been proven to be a challenge. Although company would introduce a new vision and hire new managers, probably nothing substantive changes. The problem seems to be that the culture is largely invisible to those inside of it (Hyatt, 2011). Furthermore, single fix changes such as introduction of teams or Lean production methods may appear to make progress for a while, but eventually the interlocking elements of the organization take over and the situation returns to square one (Denning, 2011). However, everything is possible, even the change of culture. According to Hyatt, first step is to become aware of the culture. After that, it is possible to evaluate what things should stay, what should go and what is missing in the culture. When these things are ready, it is impossible to envision a new culture and start sharing the vision with everyone. This phase cannot be emphasized enough; one must keep casting the vision until it takes root and begins to grow. Finally and most importantly, one must get alignment from the leadership team. If the leadership team will not buy the vision and not be willing to take a stand to make it happen, the change will most certainly fail. (Hyatt, 2011)

Hart and Berger (1994) introduced an idea, that corporate renewal and developing organization demands simultaneous improvements in several elements. Essential elements were found to be;

- A holistic view of the organization
- An endeavor to accomplish improvements on variables such as;
    - Cost, quality and lead times
    - Customer and vendor relations
    - Utilization of technology
    - Organizational arrangements and
    - Employee learning and competence development.
- A dynamic and long-term perspective on the change processes
- A development of the work itself and work related tasks
- Increased decentralization of responsibilities

Beer *et. al* (1990) introduces two different models of corporate change. A traditional, hierarchical way called **programmatic change approach** and more employee oriented called **managing corporate climate approach**. The research argues that traditional change program will not be able to succeed in key elements of changes with co-ordination, commitment and competence due to off-the-shelf standardized solutions, top to bottom style leadership from headquarter and its focus on only one particular human resource instead of larger perspective. However, managing corporate climate concentrates on centrally co-ordinate change instead of efforts from far-distance such as company headquarter. This inside-out type solution is found to be much easier for employee adaptation.

3.4.1 Case example: ABB T50 program for corporate renewal

During years 1991-1993 ABB Corporation’s goals with the help of T50 program was to turn around an old and large corporation including over 30 000 employees characterized by bureaucratic routines and hierarchical organization. The name for the project, T50, became from the project’s goal of reducing the lead time by 50 percent. The challenges in recruitment, absenteeism, personnel turnover as well as increasing demands on shorter lead times, high quality and customer orientation were key drivers behind the project. The objective was to create a flexible organization in which committed personnel can increase the customer value in terms of shorter cycle times in all customer related processes in the corporation. (Hart & Berger, 1994, p. 27-28)

The program was based on two central themes; **decentralization and competence development**, which were supported by the ultimate goal of lead time reduction. The goal for decentralization was to implement multi-functional teams responsible for the entire customer order process from the order reception to shipment and invoicing. Furthermore, competence development was a major part of increasing employee professionalism. The competence development was achieved due to wide range of on-the-job training, education, courses and seminars that employees participated. Finally, it enabled the change of managerial practices to roles where coaching and developing the personnel were primary responsibilities. (Hart & Berger, 1994, p. 29)

The key indicator for projects success was the reduction of lead time. In addition, shorter lead times were seen to generate other positive factors such as higher productivity and decreased fixed assets. Therefore, these overall performance measurements were involved. Prior to the project, the Swedish consulting firm Indevo made calculations to estimate the effect of a 50 percent reduction of manufacturing lead time. The results were:

- Manufacturing cost -8,5 %
- Productivity +10%
- Fixed Assets -15%
- Work in process -47%

(Indevo, PIMS research, 1991)

In the case of ABB, in three years the results in the company were;

- Cycle time -47 %,
- Productivity +9 %,
- Work in progress -20%.

To sum up, the development was achieved through successful implementation of building a democratic relation between hierarchical levels and democratic distribution of power. (Hart & Berger, 1994, p. 42) In addition, a clear relationship between operations cost and lead time were found. (Hart & Berger, 1994, Indevo / PIMS 1991).

3.5 Value Stream Mapping

Value stream has a simple definition; whenever there is a product for a customer, there is a value stream. (Rother & Shook , 1999) Furthermore, Value Stream Mapping (VSM) is a principle to analyze the necessity of operations to deliver a service or a product from customer's point of view (QDC training material, 2013). When starting an improvement project, one of the challenges is defining on what things to concentrate. Value Stream Mapping is able to clarify what to focus when starting an improvement project (Nash & Poling, 2008, p.17). Finally, the basic function for VSM is defined slightly differently in different sources. Nash & Poling (2008, p. 2) and Arbulu et- al. (2003, p. 165) defines VSM as a tool to picture and analyze the process. Rother & Shook (1993) emphasize the change perspective of VSM as a tool to implement the future state.

Although major lean principles are highly derived from Toyota Production system, the case with VSM is slightly different. The original name with Toyota was "material and information flow analysis" and it was clearly focused on these subjects. Therefore a straight connection between VSM and Toyota's material and information flow analysis cannot be derived. The ideas of Toyota's material and information flow analysis were later on popularized by the book Learning to See. This books original title was Material and Information Flow Analysis for Lead Time Improvement and work place Kaizen. The problem with this new catchier title is, that it does not clearly object what the workbook urges the reader to see. The book is about learning to see what is the primarily a material and information flow problem. With TPS, these means Just-in-Time production principles such as flow, takt time and pull production. Furthermore, this means that another TPS pillar Jidoka (or Autonomation) is not included at all in VSM. To sum up, VSM concentrates on **material** and information flow component and ignores other M's of manufacturing (**man, machine and method**). Therefore, before using VSM or any other lean technique in any situation, the exact problem should be first identified and then selected the right tools for that certain purpose. (Smalley, 2005)

The purpose of a value stream mapping is to separate value adding operations from non-value adding operations. Furthermore, non-value adding operations can be divided into two categories, to the ones that are necessary due to current facilities and to the ones that can be eliminated immediately (QDC training material, 2013). The actual process happens through value stream maps, which are drawn as pictures of the process. The idea is to describe the current reality and future goals of operations:

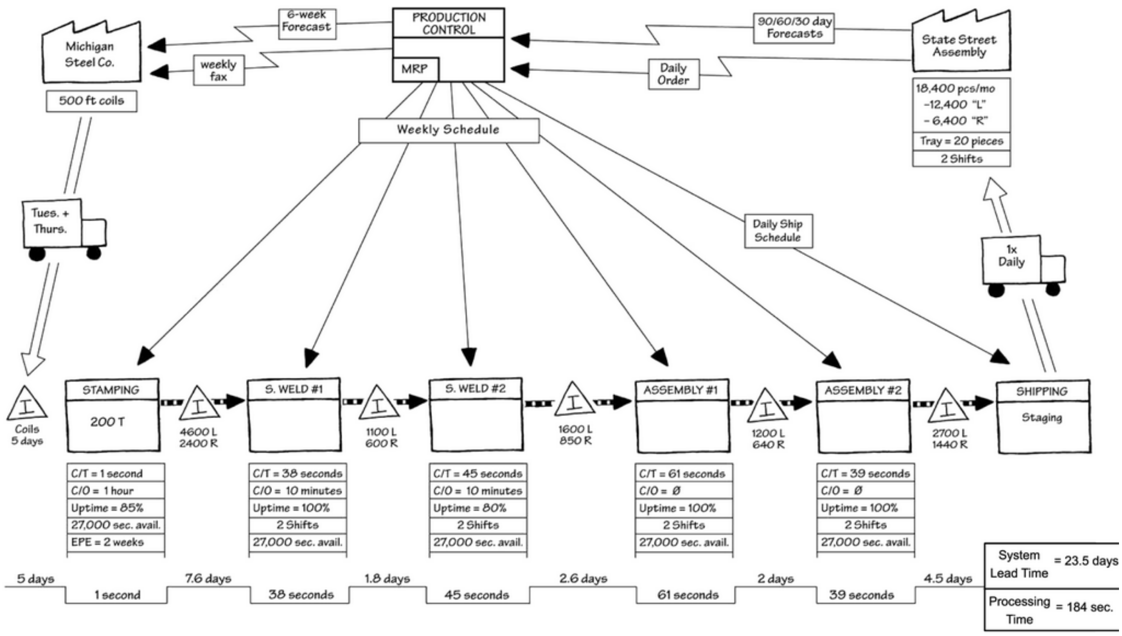
- The Current State Map – the baseline view of the existing process
- The Future State Map – the vision of the future after the improvements have been made

  (Nash & Poling, 2008, p. 2)

Value Stream Mapping has three different sections: process flow, communication flow and timelines & travel distances (Nash & Poling, 2008, p. 2). Process or production flow shows the movement of products, inventories and the resources used to execute the production. The drawing of a process flow should be started from the shipping end and thereafter working upstream in the process. This way the drawing is started from the operations linked most directly to the customer, which should set the pace for other processes upstream. (Rother & Shook, 1999, p. 14)

Communication flow is a section, which separates VSM from traditional process-mapping techniques. With this, VSM enables to connect both transactional, communication and production information in one picture. (Rother & Shook, 1999, p.16)

Timelines and travel distances represent the most fundamental information about VSM. The upper time number shows the actual lead time each operation uses. At the end of the line there is a total summarized process lead time. The bottom number indicates the cycle time of each operation. Cycle times can be replaced with the labor content. Regardless whether cycle time or labor content is being used, the total sum is calculated with the same manner as lead time. (Rother & Shook, 1999, p. 6) This comparison between lead time and production value add time is the core idea of VSM. Furthermore, this leads to goal of eliminating everything non-value adding (Smalley, 2005, p. 5). An example from VSM is shown in picture 13.



Picture 13. Demonstration of Value Stream Map (Emiliani &. Stec, 2004)

One practical aspect of VSM is the ability to choose the level of details included. One option is to map at very high level with little amount of details. On the other hand, it is possible to drill down to provide as much details as needed to satisfy the original reason for creating a map (Nash & Poling, 2008, p. 39)

Future State map is a vision where company could be after the improvement actions are being made. Rother & Shook, (1999) list the following key questions to consider before mapping the future state.

- What is the takt time?
- Will you build to finished goods supermarket from which the customer pull, or directly to shipping?
- Where can you use continuous flow processing?
- Where will you need to use supermarket pull systems?
- What single point in the production will be the pacemaker process?
- How will you level the production mix at the pacemaker process?
- What increment of work will you release to pacemaker process?
- **What process improvements will be necessary to enable future state happen?**

Although value stream mapping concentrates on first hand observations, some pre-mapping data is needed to support mapping. For example, information about customer behavior and demand, frequency of supplies and employee shifts and total working hours is needed. In addition, operation's control data is recommended to gather beforehand. (Nash & Poling, 2008, p.31) To sum up, pre-mapping data usually consist about the information that is difficult or impossible to observe first-hand in reasonable time period. The idea of drawing a current state map is based on real observations, not given standard times. Finally, the final value stream map should be composed by one person and one person only. Understanding the whole flow is what value-stream mapping is all about (Rother & Shook, 1999, p.14).

4. VALUE STREAM MAPPING TO CURRENT PRODUCTION LAYOUT AND MATERIAL FLOW

The current state value stream map used for evaluating present situation is made by Metso project group. Although the current state map is primarily based on standard times and historical data without any first hand observations, the current state map illustrates present situation with adequate precision. As mentioned earlier, one of the basic principles of Value Stream Mapping is to observe the process and gather the information based on that. However, according to Nash & Poling (2008, p.121), regardless of the methods used, 70 percent accuracy is enough to cover the major points and begin the actual mapping.

4.1 Case Study, Mobile Screens Product group

The process of making the current state map started with collecting pre-mapping data from the operations. Furthermore, due to the theoretical approach chosen for the project, none first-hand observations were made after the pre-mapping data was gathered. Although this method is not recommended in the literature, the project group decided this approach would cover the major points, even without first-hand observations.

The analyzed time period was chosen to be between March 2013 and October 2013 including total of 32 weeks. This time period was chosen due to the stabile situation in manufacturing. Afterwards, new layout was introduced which eventually would have disturbed the analysis. This historical approach slightly confuses the idea of current state, because it represent the past instead of present. However, the transformation of VSM concept has expanded the ways of using this tool and any single approach cannot be defined for utilizing VSM. (Nash & Poling, 2008, Smalley, 2005). The pre-mapping data consist of following historical or current information:

- Customer deliveries
- Raw material inventory (components)
- Average product cost
- Production labor
- Process cycle times
- Work in progress
- Finished goods inventory

Customer deliveries are composed from order office data, which represents actual mobile screen deliveries to customers. This is a manually created list which factory's order office updates and normally uses to monitor shipments and their schedule.

Raw materials inventory is based on data from SAP. Each material used in production is extended to ERP and this information includes cost and delivery information and individual purchasing lead time. Furthermore, all these materials are allocated to a certain product, for example ST4.8, and therefore the summarized total inventory can be calculated for this specific product and thereafter to a certain product group.

Average product cost is also a figure conducted from ERP. Each mobile screen has one own specification, which includes both material and labor costs. By selecting only material cost from every mobile screen's production order and excluding labor cost and additional variances, an average material cost can be calculated.

Production labor is calculated from SAP extension tool called Jotbar. Each mobile screen has one own individual production order, which includes production schedule (cycle times / lead times), materials and work centers needed. Thereby, the data from each operation can be separated and allocated to a certain process phase. However, actual cycle times differ from the ones documented to ERP system. Therefore, cycle times were estimated by production managers to give a more realistic approach. This is due to certain difficulties related to primary data collected, for example subcontracting. The subcontracting has been calculated to last eight calendar days, whereas in reality it takes two days to perform these given tasks. To sum up, this estimate gives better accuracy compared to the lead time in ERP system.

Work in progress is calculated from the total inventory value based on numbers from hyperion financial management. Hyperion financial management is a computer program used to calculate official accounting figures. Total inventory value is reduced by total raw materials and finished goods inventory. Another option for calculating work in progress would have been to rely on primary work in progress data gathered from SAP from individual mobile screen products. Furthermore, due to the difficulties in allocating WIP between processes, the project group estimated that 80 percent from WIP would locate between packing and subcontracting phase and the rest 20 percent would be divided evenly to the rest operations. This estimate originates from the time periods products stay at certain operations.

After this pre-mapping data was gathered, it needs to be modified in order to suit to the VSM needs. For example, the amount of raw materials is given in the value of euro and for VSM purposes it should be the number of weeks that factory has raw materials. Therefore the following equations (4), (5) and (6) are needed:

$$\text{Raw materials in weeks} \ = \left(\frac{Raw\ material\ inventory}{ST\ average\ cost * Customer\ deliveries\ /\ week}\right) \qquad (4)$$

$$WIP\ in\ weeks\ = \left(\frac{Total\ WIP\ value}{ST\ average\ cost{*}Customer\ deliveries\ /\ week}\right) \qquad (5)$$

$$\text{FGI inventory in weeks} = \left(\frac{Total\ FGI\ value}{ST\ average\ cost{*}Customer\ deliveries\ /\ week}\right) \qquad (6)$$

The cycle time for order office processes is a calculated figure from transactional processes. The cycle time includes the creation of sales order, the verification for schedule from production planning and the finishing of order acknowledgement.

Finally, after all the needed data was gathered and modified, the actual mapping was performed. Appendix 1 shows the current state map pictured from mobile screen assembly.

4.2 Analyzing the current state map

The current state map is drawn at a very high level with minimal amount of details. Its purpose is to demonstrate at a rough operational level what is blocking the flow. The current state map concentrates mostly on process and production flow and therefore the focus is concentrated on production point of view.

In current state map the amount of raw materials inventory and finished goods inventory is significantly high. Compared to the benchmarking companies previously mentioned, the amount of raw materials is totally at another level. The amount of raw materials inventory would cover the production for 13 weeks, which leads to inventory turn of four (52 weeks / 13 weeks). In comparison, benchmarking companies have their inventory turn around 10 to 50. There are some logical reasons behind the large amount of inventory such as the change in diesel engine’s emission classes and the inventory needed for the implementing period. In addition, inaccurate forecast related to some products demand has gained extra inventory. To sum up, the amount of raw materials inventory should be reduced. Furthermore, similar problems with the forecast accuracy can be discovered in the finished goods inventory. In addition, the time period with few individual products is extremely long in the finished machines stock pool.

With production processes, the focus concentrates towards the operations near customer due to the large amount of work in progress. 80 percent of total work in progress locates between packaging and subcontracting painting. This originates partially from department’s old custom of maintaining semi-finished machines (machines build and tested, but without final painting) in work in progress to wait for the final customer. The original purpose for this was to reduce transactional processes by not moving machines to stock and thereby avoid necessary transactional processes related to those actions. In addition, one fundamental decision was to have a large inventory of ready build products in order to be able offer quick deliveries. However, the specifications of products have not stand up for the customer demand, which in turn has lead to a large finished goods inventory and the mentioned long time with certain individual products in the pool.

4.3 Conclusions from the current state map

The conclusions from the current state map indicate an uneven performance between the processes. It seems evident that the improvements in certain areas have increased the efficiency, but on the other hand created bottlenecks elsewhere. Production processes upstream concerning engine assembly and line assembly are performing well, whereas downstream including packaging and subcontracting painting in Ermail are blocking the flow. In addition, the queuing between line assembly and testing, testing and packaging and packaging and Ermail subcontracting should be able to avoid by introducing one-piece flow between these departments. In addition, the large inventories from both ends of the process should be reduced significantly. These conclusions from the current state map are essential when moving to next phase of designing a future state map and new facility layouts to support it.

The recommendations from the current state map can be compressed as following:

- Reduction of raw materials inventory by 50%
- Production lead time reduction by 50%
- Smoothening the flow in downstream process and introducing continuous flow.
- Removing finished goods inventory and moving towards make-to-order philosophy wherever possible.

Later on the actions for implementing these improvements are introduced with the future state map and the newly created future factory layout.

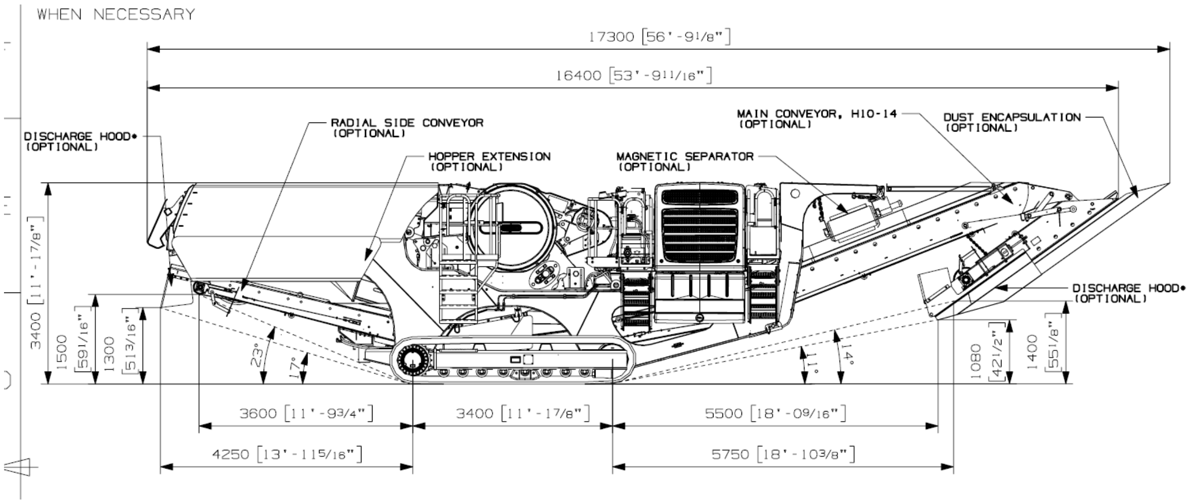
5. CREATING A FUTURE FACTORY LAYOUT TO SUPPORT FUTURE STATE MAP IMPROVEMENTS

The purpose of creating a new factory layout is to represent features how the future state map improvements would be possible to execute. In addition, the proposals for the future factory layout will be based on best available knowledge and forecast about factors such as the future customer demand and the facilities needed. Furthermore, best ideas about new layouts were gathered from all manufacturing related managers and finally combined these ideas to support the creation of a new future factory layout.

5.1 Pre-data for the Future Factory layout

The procedure for creating a future factory layout started by gathering basic information about current products and production facilities. The current data was used as a reference and as a base of setting budget and goals for new layout. The information about current products is vital when designing new manufacturing facilities. For example, the outer dimensions and lifting weights are important when locating certain products to certain production areas. Things to consider are example assembly line width, height and length, crane maximum lifting weight and overall lifting capacity of production line. In addition, the equipment for moving material to the assembly line (material handling equipment) and the method of conveying products on the assembly line should be chosen.

Defining sufficient facilities such as the height of the crane rail cannot be defined straight from the products outer dimensions. This is due to the actual assembly operations, which set restrictions to different assembly operations and sequences and therefore wider knowledge about details of assembly is needed. For example, some assemblies are installed inside or between other structures and therefore the crane lifting height must be enough to bypass these structures. Therefore, information was gathered both from product data bank and actual field measures to determine actual restrictions. In addition, production managers were interviewed for more information. An example of outer dimensions picture is shown in picture 14.



Picture 14. Outer dimensions of LT106 Lokotrack (Metso databank, 2013)

Another key figure for future factory layout are the future production volumes. The basic principle in the future manufacturing would be to shift towards demand controlled scheduling, where majority of products would have customers before actual assembly operation would start. Therefore, the manufacturing operations and the capacity should be dimensioned in a way, which would enable the capacity to be adjusted to fluctuations in demand and also to the increase or decrease of overall year scale capacity. Furthermore, appendix 2 about production volumes represents an important feature in production year scale variation in demand. It seems obvious that the production volumes vary strongly between seasons. In addition, production concentrates strongly to first two quarters, which partly originates from two subjects. Firstly, northern hemisphere customer's demand concentrates to summer months, which on the other hand schedules production to the beginning of the year. Secondly, major accounting figures such as financial statement or operating budget are usually closed during the last months of the year and therefore investment decisions concentrate on these months and the actual production follows usually shortly.

Current production facilities were studied in order to get a picture about present facilities. In addition, the information was utilized to set area goals for the future factory. These goals for future factory are based on current overall areas without any further proportions between different departments such as painting or power pack assembly.

First, areas were calculated from 2D layout model, which represent the Tampere CSE manufacturing areas and warehouses. Secondly, additional warehouse areas outside factory plant were investigated and areas were listed and documented. Finally, the area data collected from 2D layout was inspected with a laser measuring equipment to verify and correct possibly partly defective data. Picture 15 shows the 2D layout picture of current facilities.

Picture 15. Tampere CSE factory 2D layout. (Metso, 2013)

Finally, rough calculations were made to get estimates about current truck traffic and thereby the amount of inbound and outbound logistics. The reason behinds this procedure was to estimate the need for future transport docks and the areas for outbound traffic.

5.2 Creating the Future Factory layout

The creation of a future factory layout was designed to follow the manufacturing facilities design procedure introduced in chapter 3. However, due to the tight schedule given to the project and the rough level of details needed, some phases were decreased or estimates from plant managers were used. In short, the design procedure followed largely a systematic approach and in addition, notable effort was spend to analyze the pre-data and current factory facilities.

The first step of the design procedure was determining, in relation to the demand forecast, what products and what kind of volumes were going to be manufactured at the future state. The uncertainty in the future situation and forecast is always normal, and therefore forecast is only indicative. However, the forecast should be accurate enough to be able to show the trend of the production volumes are moving towards. Due to the probable variance between the future forecast and the actual production volumes, the original goal was to fit the factory's upcoming utilization rate around 80 percent. Thereby, it would enable not only decrease the production volumes when necessary but also slightly increase them without the need of redesign the upcoming factory layout.

Furthermore, a fundamental decision about shifting to two shift work was made, so the upcoming facilities would have higher utilization rate. Two shift work has several major advances compared to a single shift such as more compact facilities and the lower amount of equipments and tools needed. Furthermore, more compact facilities leads to lower maintenance cost such as snow clearance, lower energy consumption due to less cubic meters needed and higher facility utilization rate. Moreover, higher utilization rate automatically produces heat, which in turns decreases the need for external heat sources. At the current state, factory uses partially two shift work, but several line assemblies such as mobile screens operate in one shift. This originates partially from facility restrictions such as the narrowness of production lines or the lifting capacity available. In addition, the desire and motivation for fundamental two shift work has been missing and therefore the final implementation has not been executed. However, with the future factory layout and by combining different assembly departments, such as mobile screen assembly and compact Lokotrack, both the facilities and the capacity can be designed to meet the requirements and two shift work becomes a possible or even an obvious alternative.

The next phase of the design procedure concentrates on make-or-buy decisions and thereafter actual manufacturing decision how parts will be fabricated. At the beginning of the future factory project, the conceptual idea was to maintain all current departments and thereby operational functions. However, later on the project group challenged the existence of some current operations such as painting and power pack assembly. Thereby, the existences of those operations become optional. More precisely, the painting phase was previously challenged in the current state VSM due to its significantly long lead time and cost compared to the amount of value added. With the case of power pack assembly, due to the large amount of raw material inventory and consequent committed amount of working capital, project group considered changing the assembly to subcontracting. However, final decisions about the subject have not been made and currently the power pack assembly and painting are involved in the future layouts.

The following phase of setting time standards for each operations and the assembly line balancing was practically benchmarked from previous time standards. This data from previous time standards was combined with the time studies made for the company and estimated improvements in the factory’s production efficiency. The factory’s production efficiency was estimated to improve through the new, functional facilities, higher accuracy of production tasks and standard times, which would lead to a overall reduction of standard labor hours needed. In other words, this would mean reducing labor hours and increasing productivity inside factory’s operations. Eventually, these changes would require the change of the work culture and the general work standards required from all employees.

However, it must be emphasized that the improvement goals set were only tentative to give certain starting point and a goal to aim for the project. Furthermore, similar to the

ABB's T50 project, the targets for the project were set before any actual operative actions to fulfill these targets were designed.

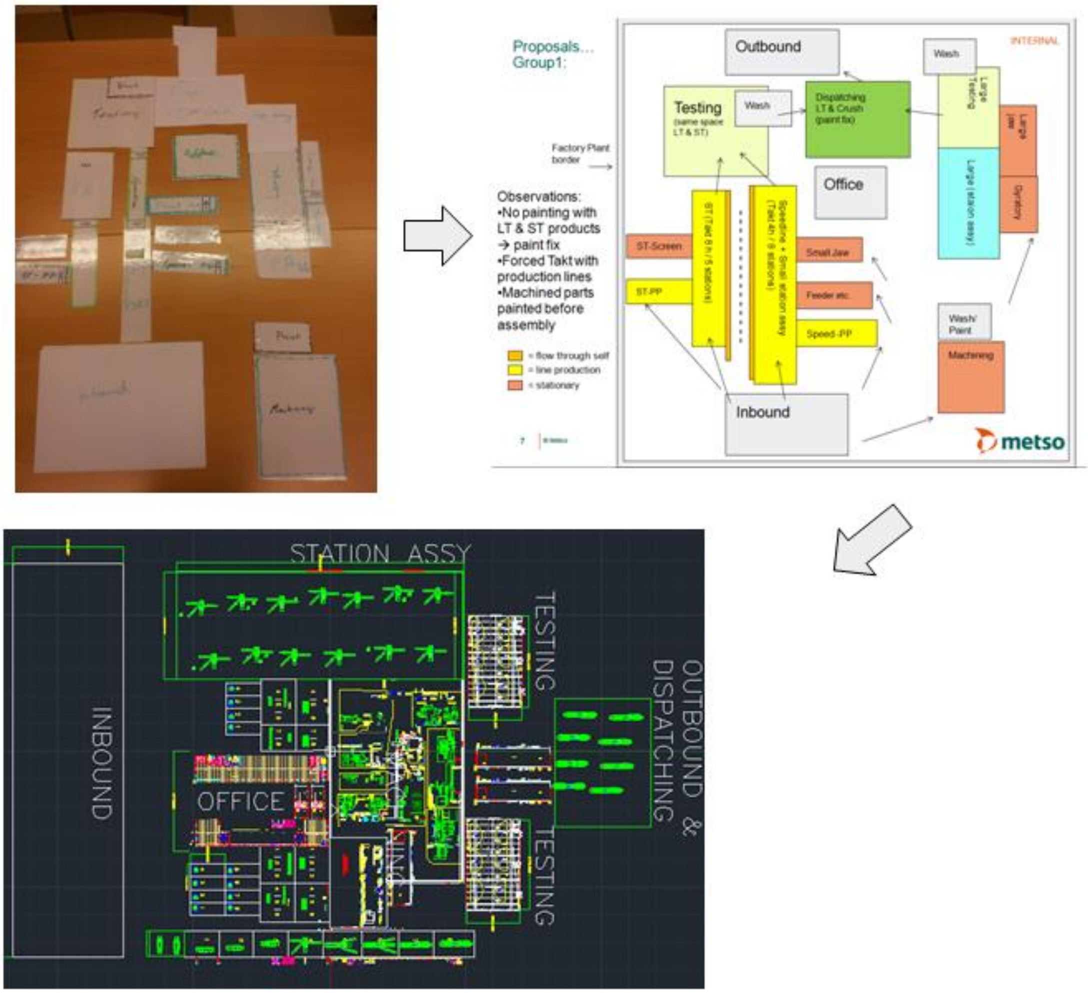
Determining the factory plant's cycle time was one of the most important conceptual decisions for the future factory. In addition, plant rate or takt time must be calculated to give a starting point for designing suitable facilities and their cycle times to meet customer demand. Currently, line assembly operations use 8 hours cycle time. However, it should be remembered that currently factory operates with two assembly lines and two station assembly departments. In the scenario where production line departments (Mobile Screens & Compact LT) would emerge, the eight hour cycle time would not produce enough machines related to presumed customer demand. Therefore, it was a natural decision to tentatively design only one production line with four hour cycle time. In addition, four hour cycle time is able to support one original target of visualization the build-up process of machines and the production flow.

Although, Metso MAC has traditionally favored cycle times related to a work shift (8h), all other possibilities are basically possible from couple of minutes up to several days. As mentioned is chapter 3, the suitable cycle time is depending on several factors such as the size and dimensions of the products and conveyors available. Nowadays, eight hour cycle time and its correlation to the length of one work shift enable the follow up of production schedule easier for both managers and employees.

In correlation to the selection of four hour cycle time, the number of work stations must meet the calculations of total labor hours designed. Furthermore, current labor hours related to products in the production lines are already optimized to some extend and therefore the number of work stations must be close to those standards. Nevertheless, new production layouts and other improvement would improve production efficiency and therefore it is reasoned that four hour cycle with double amount of assembly stations would leave available resources to production line. However, new products would be introduced in the line assembly in the future factory and most likely the amount of labor needed with these new products would be significantly higher than other products in the production line. For that reason, the partial over capacity for certain products in the production line would be inevitable for production line to be capable of managing these new products with higher labor amount needed. However, the balancing for assembly operations for different products is possible. The balance can be achieved for example with higher labor products with extra men (bucket brigade) or on the other hand by skipping some assembly stations with lighter, more simple products with less labor involved.

The remaining facility design phases from determining activity relationships to introducing final layout followed an iterative way of creating a blueprint. Due to the open field situation where no previous facility boundaries existed, project group decided to explore various solutions for a new layout. Thereby one ready-given basic concept would not capture the creativity to vision new ways off organizing assembly operations and the possibility of finding new concepts would be higher.

Eventually, four possible solutions were established from which two came from a workshop organized for manufacturing managers, one from the future factory project group and one from the thesis worker. In the workshop, the idea was to give the collected pre-data from current operations and future production volumes to participants. In addition, plastic models from current departments were given to visualize the proportions of departments. Thereafter, groups had an afternoon time to gather a layout from given departments or create totally new ones. Finally, groups represented their suggestions and best ideas were listed to support the creating of final master plan. After the manual versions about layouts were made, they were converted to digital format and further to 2D Autocad layout. Picture 16 shows the creation of layouts in the workshop and the transformation to digital format later on.



Picture 16. Creation of the new layouts

Finally, the chosen layout design was detailed with plant and personal services such as parking lots, visitor routes and offices. Different manufacturing buildings were arranged in relation to each other to optimize the use of property and simplify the building constructions. In addition, the tentative selection for material handling system was made. In future factory layout, the material handling will be partially executed with automatically guided vehicles (AGV) and partially with traditional forklifts. The introduction of ATV supports widely the criteria for selecting material handling equipment. Appendix 3 shows the final layout for manufacturing facilities.

Furthermore, a flow chart was drawn to simulate the material flow in the final layout. The wideness of lines represents the frequency and volumes of material movement. The purpose of the different colors is to represent the actions made during the movement: red indicates pure material movement without value adding operation, yellow means movement during actual assembly operations and green movement during finishing operations and movement to finished goods warehouse. Appendix 4 represents a flow chart from manufacturing areas. In addition, similar material flow chart was made from material movement in warehousing areas.

The purpose of the flow chart is to simulate actual material movements and detect possible back tracking or cross traffic spots during the process. For example, it was identified that finished products from packing department are crossing with materials upcoming to crusher assembly and machining. However, the material movement’s frequency to finished goods warehouse (outbound) is low, only few movements in a day, and therefore the cross traffic will not cause problems with the flow or the traffic safety.

5.3 Results from operation areas development

At the beginning of the project a goal for 50 percent decrease in production and warehousing areas (inside) was set. During the design procedure it was realized that this goal was slightly too ambitious. As a result, production areas were decreased by 38 percent and inside warehousing areas were increased by 16 percent resulting a 27 percent decrease overall.

The reason for the shortage in results occurs from few basic decisions. The present facilities such as production lines are dimensioned to suit ones special purpose and no extra. Furthermore, the fundamental decision of building an eight station assembly line means that the total number of line assembly stations remains the same. In other words, present two separate, four station assembly lines are combined to one eight station line. In addition, combining two different product groups to a one single production line means that the facilities must be dimensioned to suit both product groups. As a result, compact Lokotrack products have some extra space in the new production line in order to be able to execute mobile screen production in the same line. However, the previous extra space related to different station assembly departments has now been cut off, which results as a decreased amount of station assembly space.

In the case of warehousing areas the result of increase in inside areas can be explained with current loading level of warehouses, which practically means that currently all possible warehousing space is utilized. However, this causes problems with usability of warehouses. In order to improve material flow and its movement, some extra space is needed and therefore the total warehousing area has been increased. Table 2 represents the comparison between current facilities and the designed future ones.

Table 2. Facility area comparison between Tampere CSE and the Future Factory.

Area calculating	Future Factory (ha)	Current Facilities (ha)	change %
Inside:			
Manufacturing	2,20	3,56	-38 %
Inbound (inside)	1,04	0,90	16 %
Total Inside:	3,24	4,46	-27 %
Outside:			
Inbound (outside)	2,65	2,35	13 %
Outbound	0,63	1,00	-37 %
Total Outside	3,28	3,35	-2 %
Plant (property):	9,55	13,8	-31 %

Outside areas remain at the same level overall with the exception that outbound area is larger than previously. This is due to the fact, that factory has previously stored its machines both inside and outside factory plant. In the future state, all machines will be held inside the factory area and nearby storage locations will not be maintained anymore. The size of the factory plant has reduced with better building placing and by reducing the number of buildings by integrating compartments together.

6. VALUE STREAM MAPPING TO THE FUTURE FACTORY LAYOUT AND MATERIAL FLOW

Creating a future state map to the future factory layout is relatively straightforward procedure. Furthermore, by creating a future factory layout which follows the basic tenets introduced in theoretical chapters and the guidelines of Lean production methods, the probability of finding optimal solutions is high. Is short, the future factory builds on three subjects: pull scheduling from customer point of view, designing production capacity accordingly (takt time) and by introducing flow production and physically arranging processes to support these goals. However, the actions for implementing the future state map and achieving the defined goals are the challenging part. Even though, some improvements can be achieved with changes in factory layout and removing waste, the human factor still plays a major role in overall productivity. Therefore, the tools for corporate renewal were introduced in theoretical chapters and the usability of these tools will be later evaluated.

Future state map represent the manufacturing operations with the same amount of details compared to current state map. Transactional processes from order handling and supplier forecast are ignored in this project in order to focus attention to production operations. The key figures in future state map such as the amount of raw materials in weeks and finished goods inventory were calculated similar to the current state map.

6.1 Case Study, Mobile screen product group

Mobile screen production is been currently done with production line type arrangement. In addition, the power packs for mobile screens have been produced with a line assembly. In the future state map, the production continues with a production line type assembly. This is due to the previous good results related to low target labor hours reached and the improved material flow, which partly originates from line assembly. Furthermore, the continuous one piece flow from production line has been introduced between operations and the flow has been improved significantly in downstream processes concerning painting and packing.

Inventories from both ends of the assembly operations were decreased significantly, the finished goods inventory dropped to one third out of the original level and the raw materials inventory was approximately divided by half. Furthermore, the work in progress number has been decreased by 62 percent.

Production processes are mapped in a slightly modified way compared to the current state map. The assembly hours range from individual operations is now missing. The extra information it provided was unimportant and only represented the weak quality of ground data the current state map was based on. For example, the data included individual machines with zero labor hours. In addition, the combined amount of total production lead time on value adding time is now rationalized. In the current state map, the production lead time was calculated as a total from inventories (raw material and finished goods) and work in progress and the actual value adding time was excluded. This does not follow the logical idea of including the value adding time to the overall production lead time. Therefore, the future state map includes the value adding time to the total production lead time. In addition, in the current state map the value adding time is calculated for the entire product group. In order to compare it with the future state map and its value adding time, the current state value adding time must be divided with the number of products per week the factory delivers.

The comparison between weeks and days inside a week is similar to the current state map; one week is compared to the normal amount of working days meaning one week equals five days. In addition, both the current state map and the future state map are calculated with single shift operations; although the future factory has been designed to work in two-shift work. The future state map is showed in appendix 5.

The production process begins with the engine assembly, which is designed to follow a cycle time of four hours. This can be stated as a natural decision, because previously the fundamental selection about equal four hour cycle time was chosen for main production line. Furthermore, power pack assembly line supplies this main production line and therefore its capacity should match the downstream process. However, the variance of assembly labor hours between different product groups causes problems to certain products, such as mobile screens, in the production line-type assembly operations. The calculated amount of labor for mobile screens resulting from power pack assembly line slightly exceeds the targeted labor hours with manually controlled engines. However, several ways of balancing the assembly line exist and the targeted labor hours can be reached. For example, this balancing has been executed with the final assembly, where mobile screens use only six stations from eight stations available. The remaining two stations enable products with heavier labor targets to suit into the production line, for example Compact Lokotracks. Furthermore, in the case of mobile screens, this causes a short first in-first out (FIFO) type queuing in the end of the assembly line. However, with four hour cycle time this results an acceptable eight hour or one day delay in the lead time.

The testing procedure is shortened to two thirds of the original length. This has been a fundamental decision of moving from process testing to more straightforward, functional checklist-type procedure. Currently, the testing schedule has included some process testing without active involvement from operating employee. This process testing has not increased any value to testing procedure or to final customer and therefore the decision of excluding it was made.

The finishing operations including wash, painting and dispatching had originally the most attention due to the lack of continuous flow and the significant portion of work in progress during these operations. Similar to the testing operations, the function of the final painting was challenged. After the research made for the future factory, the present procedure of final painting was decided to transit to local, fixing type painting. Furthermore, the designed 8 hour cycle time for painting operation including wash is sufficient for selected fixing type painting. In the case of a need for traditional total painting, the lead time schedule must be changed.

The need for painting occurs from factory's own operations, because all the needed parts for mobile screen assembly are delivered with a finished coating. Therefore, things such as material movement inside the factory and handling during the assembly operations are the root causes for painting. Roughly speaking, half of the materials are painted and half galvanized. Galvanized surfaces are more durable for outer abrasion than painted ones. Nonetheless, galvanizing has certain challenges such as larger modules are difficult to hot dip galvanize and the visual appearance of large surfaces is lower compared to painted ones. However, whether the parts are galvanized or painted, the attention to material handling must be made to exclude final painting from production processes.

The last operation of packing has transformed its function from partial packing, which only enables transport to subcontracted painting outside the factory to the level where machine is ready for shipment to customer and all the selected stickers, equipments and protections for delivery are being made. Therefore the packing operations duration has been extended to eight hours from previous four hours.

6.2 Results summary from the value stream mapping

The results from value stream mapping can be gathered with a Value Stream Box Score (Maskell & Baggaley, 2003, p. 61). Value Stream Box Score enables a simple comparison between current and future state map and shows the change in the lead time and in the value adding time. In addition, the value adding proportion is included outside the original Value Stream Box Score to emphasize the change of this important ratio. Appendix 6 represents the mobile screen production box score.

The production lead time has decreased significantly by 63 percent. The majority of improvements come from major decreases in raw materials inventory and finished goods inventory. In addition, the lead time between packaging and painting is now shortened with the help of straightforward one-piece flow.

The value adding statistic indicates that the value adding time would decrease by 16 percent. Nevertheless, this should not be interpreted automatically as a negative result. A logical decision would be that the decreased amount of time in value adding operations would decrease the amount of value to customers likewise. However, this statistic does not consider the basic question of defining what really a value adding operation is? For example, can painting and packing be described as a value adding operation? The current state map assumes that every operation performed would be a value adding operation. However, in the future state map the classification of whether or not an operation adds value has been transformed to customer point of view. Finally, this results a smaller amount of hours with equal amount of value.

The value adding proportion is improved by 16 percent. This can be viewed as a good result although the majority of improvement is due to the amount of inventory decreased from raw materials and finished goods. Furthermore, this is a typical phenomenon with a company, which has large inventories, but relatively good production processes. The inventory represents a great portion of total capital involved and therefore the strength of making a difference in overall results is much higher than shortening the actual assembly operations.

6.3 VSM's usability to evaluate production processes

VSM's ability of describing the change in production processes lead time and value adding time was successfully implemented. The required abilities from VSM such as describing factory's performance with indicators related to production lead time, value adding time and capital in inventories were suitable in this particular case. In addition, VSM has the ability to show, what kind of problems processes are facing in the big picture (Current State Map). Furthermore, VSM is an effective tool of visualizing future opportunities and how things should be made (Future State Map).

Although Value Stream Mapping has proven its efficiency related to material flow and describing different processes, it is missing an economical perspective in a detailed level. Furthermore, things such as the levels of finished goods inventory and raw materials inventory can be selected without any detailed calculation. However, what happens to things such as fixed cost or factory labor hour rate when the whole infrastructure will be redesigned? Furthermore, what is the total cost of value adding operations with the new labor hour cost? These kinds of detailed economical questions cannot be answered with the help of VSM.

One of the basic rules related to investments is that they must be cost justified. This has raised the need for more detailed cost calculations and defining certain economical figures. Therefore, basic concepts about operative cost accounting will be introduced in the chapter 7 and then utilized to calculate the economical impact of the Future Factory.

7. CALCULATING ECONOMICAL BENEFITS FROM IDEAL LAYOUT

Value Stream Mapping was proven to be an effective way to illustrate the improvement in the material flow with the Future Factory. However, the financial impact of changes was largely missing from VSM's review. In order to be able to evaluate the efficiency of Future Factory's operations in an economical perspective, financial calculations should be made. In addition, the applied calculations should follow Generally Accepted Accounting Principles (GAAP) so they could be compared to current calculations. In the case of the Future Factory, the basic calculation of economical benefits has been designed to be a three step procedure. Firstly, with the help of table about factory's cost of goods sold and the knowledge about Future Factory facilities, fixed and variable cost for the future factory will be defined. Secondly, by using lead time, the number of employees and efficiency factors related to the Future Factory, the amount of labor needed in departments will be calculated. Thirdly, with the help of estimated labor amount in the Future Factory and current Tampere CSE manufacturing, hour rates and thereby financial improvements for different departments will be calculated.

7.1 Cost accounting definitions

The cost accounting should always follow previously mentioned GAAP principles. According to Cunningham & Fiume (2003) the instructions include following principles:

- Objectivity – the numbers should be based on objective evidence
- Materiality – the significance of a certain aspect should be considered when it is reported
- Consistency – same accounting principles between periods should be used
- Conservatism – when different scenarios occur, the least favorable should be chosen.

In short, accounting should be made in a way, which would give realistic and comparable information about company's economical state between different time periods. A common challenge in accounting is to define, which expenses should be allocated, for example, to certain products, product groups or departments. This problem can be resolved with a matching principle. Matching principle requires that expenses related to certain revenues must be combined in order to get a report of operations profitability in a specific time period. However, typically matching principle cannot be optimally executed and best estimates are being used. (Kiistama & Jyrkkiö, 1991, p.54)

Making business or making money at the end comes down to two figures; incomes and costs. In the Future Factory case, the focus is on the cost point of view. This is due to the fact, that income from sales operations can be stated as a constant, because sales volumes and selling prices stay at the same level in this scenario.

Likewise, costs can be divided into two separate categories: fixed and variable costs. Fixed costs are depending on the capacity of a factory and the period of time. For example, facility rents, heating expenses and staff salaries can be viewed as a fixed cost. Fixed costs cover the basic operational preconditions and thereby enable products to be manufactured. Therefore, the fixed costs remain basically the same regardless the amount of products made. On the other hand, variable costs are the costs that change according to the production volumes. Materials, blue-collar salaries, supplies and tools are examples from variable costs. However, today’s blue collar salaries are not totally variable due to the strong collective labor agreement, which protect the workers and prevents real time adjustment. (Kiistama & Jyrkkiö, 1991, p. 68-74)

In this economical situation with the Future Factory profitability, basically all costs are variable in the transition phase. This is due to the new facility and organization infrastructure, which results as a totally new cost structure. Therefore the focus concentrates on finding ground reasons for different cost accounts in order to be able to define how the cost structure has been formed and how it will reform in the Future Factory.

7.2 Future Factory cost of goods sold

The Future Factory cost calculations are based on cost of goods sold statement. The cost of goods sold statement represents the comparison between targeted and calculated cost for a certain time period. In other words, in the case of future calculations, the variance is zero, whereas past calculations typically have variance due to the changes such as production volumes or the amount of labor used.

The cost of goods sold-statement is divided into three sections. Sections 1 & 2 represent the targeted cost accounts and section 3 indicates the actual manufacturing operations. With the help of finding root causes for the fixed and variable costs in the current Tampere CSE operations, it is possible to estimate the similar accounts in the Future Factory environment. Table 3 represents the different accounts that are involved in the section 3 and the percent difference between planned Tampere CSE operation and similar accounts in the future factory in year 2014.

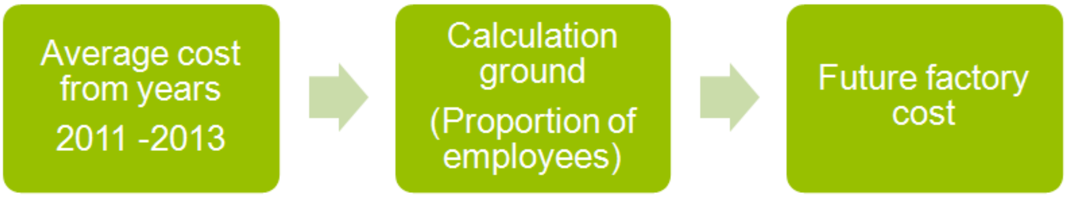
Table 3. Cost comparison between Tampere CSE and Future Factory operations.

Absorption	Tampere CSE Planned 2014 vs. Future Factory [change %]
Materials & Supplies	-10 %
Direct labour	-50 %
Indirect labour	-53 %
Operational support cost	-47 %
Rents	560 %
Energy expenses	-50 %
Plant depreciation	-54 %
Local allocations	-57 %
Total	**-38 %**

The accounting principles of how certain accounts have been calculated are suited individually. Furthermore, if accounts have previous calculating formulas those have been followed in order to maintain consistency inside accounts. In addition, inside accounts the materiality principle has been executed in order to simplify the calculation. For example, in materials and supply, freight during the process represents 37 to 61 percent of the total cost, depending on a year. Thereby, by following materiality principle an approximate of 50 percent can be used to calculate Future Factory cost with enough accuracy in this individual account.

Tampere CSE accounts for 2014 are derived from factory's official accounting numbers and they are individually defined for the year 2014. Therefore, due to the individual investments or projects, the variance inside accounts between different years can vary significantly. In order to calculate realistic costs for the year 2014 in the Future Factory, calculations have used averages from previous years in order to define the realistic levels of costs. Finally, by using different calculation grounds for each account, the final Future Factory numbers were calculated. The diagram 2 shows an example from calculating Future Factory cost accounts.

Diagram 2. An example procedure for calculating Future Factory cost.



Labor costs are derived from the number of employees. More precisely, direct labor is related to the number of blue-collar workers and indirect labor to the number of staff and material workers.

Operational support cost however is a combination of accounts such as maintenance of buildings, IT-expenses, traveling and other production related expenses and therefore the calculation ground consist of several grounds. For example, maintenance of building has downsized to 20 percent from the original level. This is due to the decision of moving into rented facilities where only local improvements are on tenants' responsibilities. Furthermore, IT-expenses and travelling are calculated from the proportion of white collar employees, because that is the part of the employees which use those services. Other production related expenses account includes costs such as work wear and transporting hazardous waste. Work wear is related to the proportion of blue-collar employees and transporting hazardous waste to the production volumes. These all grounds and expenses have their own weight in the calculated cost level for operational support cost.

Rent and plant depreciation are strongly connected to each other, because high portion of depreciation comes from the factory buildings. In the Future Factory, facilities are rented, which naturally increases dramatically the amount of rent. The amount of rent has been calculated from the average rent of square meters for office, manufacturing and warehousing facilities by multiplying it with the areas calculated in the layout design.

Future Factory's plant depreciation comes from the machining center investments, which have depreciation period of 10 years. Energy expenses are calculated with the proportion of current and Future Factory inside areas and considering a 30 percent improvement in energy efficiency from modern building and lighting solutions.

7.3 Defining Future Factory's total hour rate

The first phase of calculating Future Factory's economical benefits is now finished. The fixed and variable manufacturing costs have been calculated and thereby the total absorption. The next phase is to calculate total hour rate, which represents the total cost of one labor hour. In short, total hour rate can be calculated by dividing total absorption with the amount of labor hours per time period. Therefore, lower hour rate is always better than higher hour rate, because with the lower hour rate the importance of a single hour is less significant and the variance caused by the same hour amount is smaller.

Furthermore, with the information about total hour rate it is possible to calculate the economical improvement for a certain production department, for example for the mobile screen products. The starting point for the Future Factory's hour rate breakdown is the planned hours for Tampere CSE production. Each individual department has one own amount of planned total hours, which can be summarized to get the total hour amount for the year 2014. On the other hand, the labor hour proportion for individual product groups has been calculated between Tampere CSE and Future Factory operations. This calculation is based on two different informations: the targeted standards hours in Tampere CSE assembly and routing and manning in the Future Factory, which summarizes the targeted labor amount in the Future Factory scenario. Although, different models inside one product group have different target hours, the calculated proportion from one model has been extended to cover the whole product group. For example, the calculated improvement from ST4.8 can be extended to cover the whole ST-product group.

However, improvement in every department such as machining cannot be calculated through this procedure. Therefore, the amount of hours for these operations has been estimated with the help of fundamental decisions made for the Future Factory. For example, the amount of hours for a new product development has been increased with 50 percent in order to strengthen the launch of new products. Likewise, the reduction of rework hours is one of the core ideas in Future Factory concept. Appendix **7** represents the calculation of Future Factory labor amounts per department.

Finally, with the information about the amount of labor hours and the previously calculated total absorption, it is possible to calculate the total labor rate for both situations. Total hour rates are represented in appendix 8.

The savings per department can be calculated by multiplying the amount of labor needed with the total hour rate in Tampere CSE and reducing the Future Factory costs calculated in a similar way. Total savings are represented in appendix 9.

The comparison between Tampere CSE current setup and Future Factory indicated a significant amount of potential in the Future Factory from the cost point of view. Furthermore, if some of the previously mentioned improvement percents in departments are found unrealistic or too ambitious in later inspections to fulfill, they can be adjusted and the created calculation model automatically calculates new key figures. In addition, the effect of different scenarios can be simulated with the iteration quality involved in the calculation formula. For example, the changes in the labor costs or in the amount of rents can be easily simulated.

8. CONCLUSIONS AND RECOMMENDATIONS

The Future Factory project is a great opportunity to the organization to visualize new methods of doing things and changing current habits and policies. This kind of project enables the factory to question all current procedures, whether or not they are plausible in a short term or not. This master's thesis has been made to guide this project and to calculate the operational and economical benefits enabled through the Future Factory concept.

The Future Factory concept has gained large attention inside the company and the reception has been positive. In addition, an effort of copying best ideas from the Future Factory to the current Tampere Crushing and Screening Equipment manufacturing has already started. This can be stated as an extremely positive direction, because after all, the most important thing is to introduce these new ideas to practice and start using them.

8.1 Accomplishing project targets

The project's original targets were to design totally new production layouts and calculate its benefits in comparison to current operations. Later on, the definition of benefits was specified considering both operational performances concerning production lead times and financial indicators related to fixed and variable manufacturing costs. The target of analyzing the designed Future Factory layout in different economical scenarios was excluded from this project. However, it might become an interesting aspect to investigate, if the implementation of the Future Factory concept as a whole becomes current.

8.1.1 Designing the Future Factory layout

The creation of Future Factory layout was a multi-phased process. The process included research about current facilities, benchmarking new ideas from factories outside Metso Corporation and multiple iterations with tentative master layouts created for the Future Factory.

The target for Future Factory layout can be compacted to one goal: improving material flow inside the factory. This goal was achieved not only through calculated figures related to production lead time but also material flow patterns pictured from the new production layout. The target of reducing manufacturing areas by half was not totally achieved. However, the final result of 27 percent decrease from current facilities can be stated as a realistic level for future manufacturing areas.

The idea of organizing processes in a way, where the amount of transfers and the distances between sequential tasks would be minimized, was greatly achieved. This is one of the fundamental purposes related to facilities design, especially if the production is designed to follow Lean principles. The processes must be designed in a way, which supports naturally continuous flow and thereby prevents intermediate storages.

In order to move Future Factory concept to a more detailed level, 3D designs should be introduced. The previously mentioned Autocad Factory Design Suite or suchlike CAD design software is highly recommended tool for further iterations. However, two dimensional (2D) models represented in this project can be used as a starting point for these designs. Furthermore, the possibility to convent current 2D sketches to 3D should be investigated.

8.1.2 Calculating operational and economical benefits

The operational efficiency was calculated with the Value Stream Mapping. Value Stream Mapping was recognized as a suitable tool for describing the change in operational efficiency due to its two phase approach with Current and Future State maps. Its simplified way of representing problem places in the manufacturing process is by far the best quality in VSM. By that means, it served well in its originally designed purpose in the project of describing the change in operational efficiency. Thereby, perceived features that were noticed from VSM in the Future Factory project largely followed previously made observations in the industrial literature. Generally in the literature, VSM has been stated to be a suitable tool for redesigning production processes. (Lasa et al (2008) & Gottmann et al (2013))

However, later on in the project when the financial performance measurement was needed, the lack of detailed information about manufacturing costs was largely missing and therefore the traditional cost accounting was included in further investigations. Although VSM has been commonly used for its material and information flow purposes, its previously mentioned lack of economical perspective has not gained attention in the literature or publications until now. However, recently published study has transformed the idea of the VSM to match to the need of evaluating production development projects in overall. The research emphasizes that the costs related to production in VSM are contemplated only indirectly, for example waste in terms of overproduction or throughput time in terms of transportations, whereas they should be direct costs such as wages. In addition, the research argues that the supportive and administration costs which are excluded in the VSM form a major part from the company expenses and therefore they should be included in the evaluation. Finally, this new model includes one-time and recurring expenses that are connected to the value stream transformation. As a conclusion, this newly created model could eventually replace the use of both the VSM and traditional accounting in the case of evaluating development project. (Gottmann et al (2013). Finally, with previously mentioned qualities the newly created model could have been extremely suitable for Future Factory concept and the usability of this new model should be investigated if the Future Factory implementation becomes current and the need for updated calculations occurs.

The calculated decrease of 63 percent in total production lead time and the 40 percent decrease in assembly lead time in the mobile screen assembly indicated a strong development potential in current operations. Although the major portion of the decrease in total production lead time results from the decrease in raw materials and finished goods inventory, the calculated 40 percent decrease in assembly time indicates the amount of potential improvements in that sector.

The economical benefits related to the Future Factory concept were finally calculated through traditional cost accounting method. The calculations rely strongly to the change of cost structure related to the Cost of Goods Sold (COGS)-sheet introduced in the chapter 7. The results in total absorption lead to a new Future Factory total hour rate, which enables the cost comparison between current operations and the Future Factory. Furthermore, the reduction of 38 percent in total absorption indicates significantly lower cost structure compared to current operations. Furthermore, with this new cost structure, the production volumes are designed to stay at the same level.

The calculated results compared to previous corporate renewal programs were similar. For example, the Indevo/ PIMS-research stated that the reduction of 50 percent lead time would result an 8.5 percent decrease in total manufacturing cost. In the case of Metso Tampere CSE and the Future Factory concept, the average reduction of 50 percent result a 7 percent decrease in manufacturing cost, including both material and labor costs. Although the calculation model has been created to serve this selected static situation and it does not separate the changes in fixed or variable costs, but concentrates mostly to the overall cost structure, it represents the change between the current operations and the Future Factory with a sufficient accuracy.

8.2 Recommendations

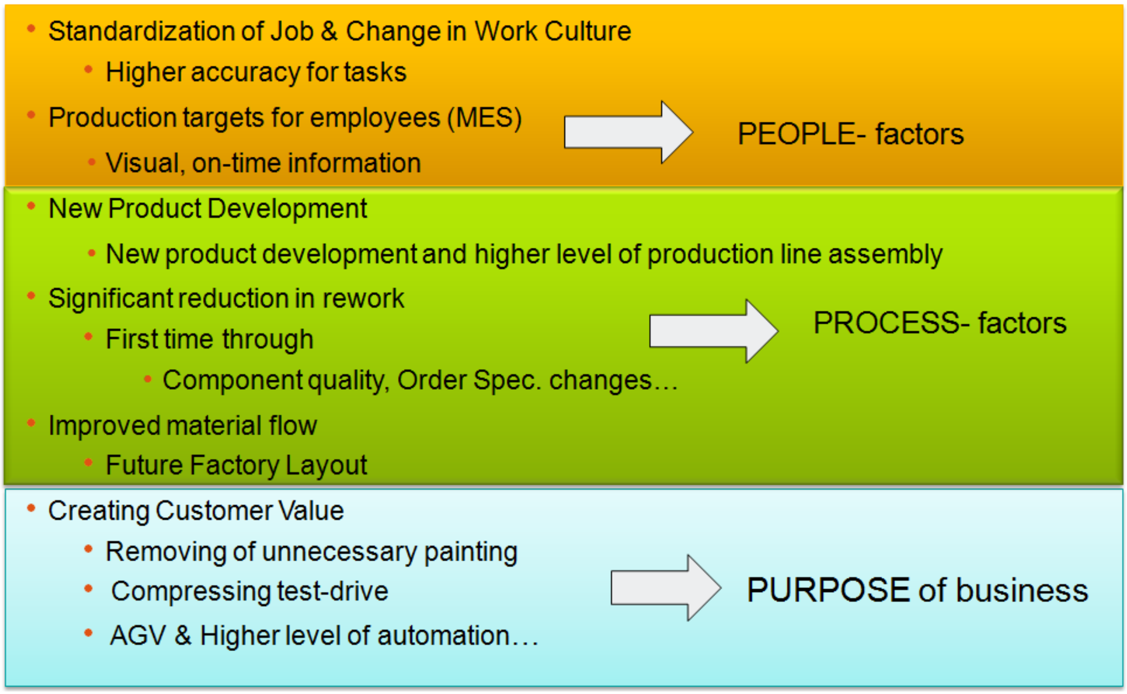
These recommendations concentrate on developing the current Tampere CSE manufacturing operations closer to the Future Factory ideology. Furthermore, the change will not happen only through changes in the facilities but also changes in work culture and in the human productivity is required. Therefore, the factory must prove its ability to develop its performance in current facilities in order to justify large investments such as the creation of the Future Factory infrastructure.

8.2.1 Manufacturing operation

The change in manufacturing operations has proven to be a challenge. The difficulty in implementing a sustainable change in large corporation follows the old Newton's Second Law of Motion, F = ma. The "F" equals to the force, "m" is the mass of an object and "a" is the acceleration. In other words, to be able to change the direction (acceleration) of a large corporation (mass) a significant strength (F) is needed. However, there are no short-cuts to successful development; operations need to be changed one by one, by doing right things every day.

The most recent example from this challenge is the Norwegian multimillion dollar project called IDEEL FABRIKK ("Ideal Factory") (Knutstad et- al. 2009). The project's aim is to create an ideal manufacturing concept for high-tech and mass customized manufacturing. However, the results have not been groundbreaking yet. The idea has been effectively combine the human and technological factors, named Attractive Manufacturing. In other words, the proposed idea is to use the available resources as effectively as possible. In that perspective, the project only reproduces the ideas created in a certain Japanese car manufacturer decades ago. However, it is obvious that today the alignment between actual processes and IT systems such as ERP are far from optimal. For example, the benefits from SAP and its subsystems have not been utilized.

One option of starting the change in the current operations is to start with the key drivers introduced in the Future Factory project. These drivers represent the methods which enable the operational development in the Future Factory. Although the drivers are specified to the Future Factory, majority of them can be used also in the current environment. The picture 18 represents the key drivers and three different categories they are divided into.



Picture 17. Key drivers for implementing corporate change.

The key factors are divided into three categories of people, process and purpose. The traditional, old fashion framework of strategy, structure and systems has largely lost its effectiveness in today's environment. In the old, high-growth environment, the discipline and focus the framework offered was needed, but the current challenges related to overcapacity and intense competition require a different approach. Today, employees' daily activities are extremely fragmented and systematized and the overall purpose of the business has been lost. It is the purpose why an organization exists, not the strategy. Furthermore, process and people factors support the overall purpose of a corporation more naturally than system and structure factors. (Bartlett & Ghoshal, 1994)

The first category is the People factors. The importance of employee commitment and human productivity cannot be overstated. In addition, things such as recruitments and keeping human knowledge and expertise become major aspects. Inevitable the change in human productivity needs changes in the overall work culture and the required level of doing. However, the need for a change must be communicated through realistic targets and they must be visual and available for everyone. One potential tool for visualizing these targets to employees is Manufacturing Execution System (MES).

Secondly, in order to gain profit from people factors, the process factors must support these people factors. For example, the investments to new product development would achieve multiple savings in actual production period. Furthermore, the idea of doing things right at the first time should be highlighted. A good example is the current idea of doing stock machines to wait for upcoming customer orders. However, the specifications of stock machines do not match with the customer demand and therefore the usability of them is low. Instead, the factory should improve its production lead time in a way, which would enable products to be delivered with the Make-to-Order principle.

The final stage, improving material flow in the current facilities can be a challenging task. However, by doing re-layout in the current facilities and by removing all the unnecessary tools and parts, which are not required in the process, improvements can be made even with small investments.

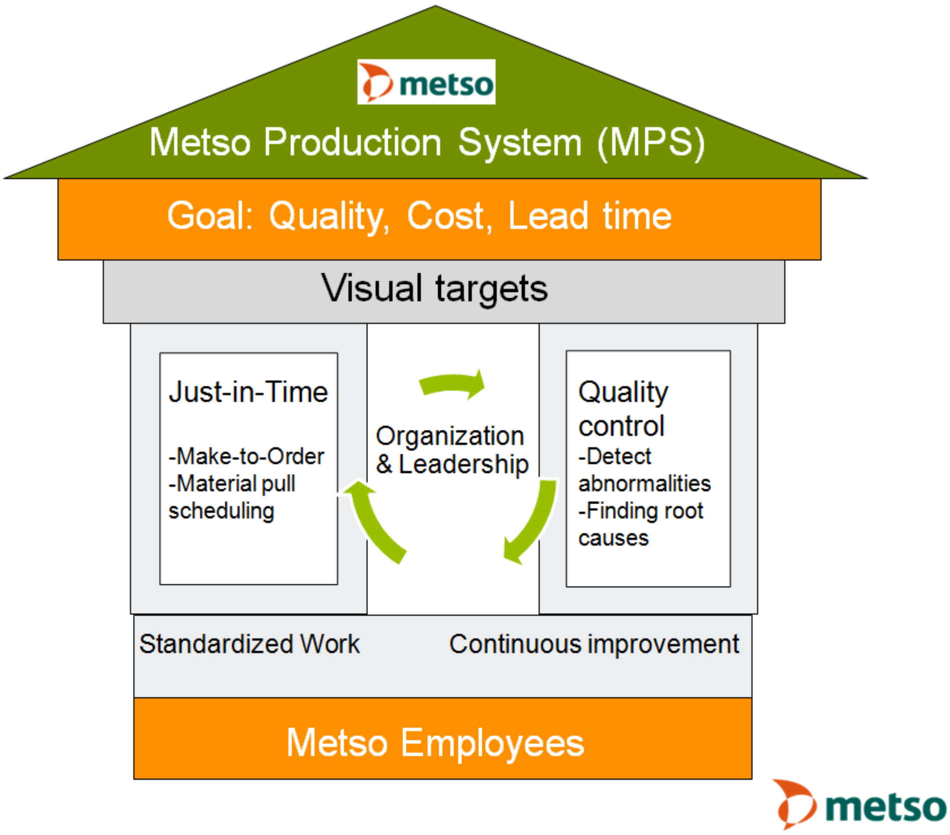
Finally, the fundamental considerations from customer's point of view should be made, what operations truly add value. A good example is the final painting mobile platforms currently use after the assembly operations. Only by raising the actual process to the level it is theoretically designed to be, factory is able to exclude the final painting and thereby reduce manufacturing cost significantly without reducing any value from customers.

8.2.2 Lean implementation

The Lean production philosophy introduced in this master's thesis has already started to develop in the factory from multiple sources. However, the guiding factor has been missing and the different participants have done simultaneously similar projects. In addition, the great majority of employees are still unfamiliar with the Lean concept and how it affects everyday life. At the moment, the Lean project has appeared to employees as an effective, but expensive cleaning operation through the Lean 5S project. However, in reality this is only a small fraction what Lean is all about. Therefore, the Lean coordinators, which represent the most recognizable part of company's Lean project, should strongly inform others and spread Lean principles to other employees. After all, now when there is momentum related to launching Lean ideology, the likelihood of successfully introducing Lean is much higher.

One possible option would be to gather basic information about the principles and tools being used in Lean to a pocket size notebook. This notebook would be given to all employees and they could familiarize themselves with the ideas related. Thereafter, the amount of people and the portion of employees would considerably grow. In addition to the Lean notebooks, information to TV-screens and bulletin boards around factory could spread Lean information.

Metso Corporation's mission and vision should be modified to suit Lean ideology. Thereby, the Lean philosophy should be visually presented to employees. Picture 18 introduces a sketch from Metso's version out of traditional TPS house, which visually represents the new mission and vision of manufacturing operations.



Picture 19. Metso Production System (MPS).

The process of making a change in the corporate culture is a long path. One master's thesis cannot change it alone. However, master's thesis is an excellent way of inspiring the company to questions its own habits and standards of doing things. Although, this master's thesis introduces large conceptual ideas which basically rebuild the whole process, the change should start from every single operation performed today.

$$F = ma \tag{7}$$

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APPENDICES

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